Chem & Met

MAY, 1942

CHOCK-FULL OF SOAP AND POTENTIAL DYNAMITE

Since LeBlanc and Chevreul laid the early foundations for the modern soap and glycerine industries there have been many changes in processes, raw materials and equipment. Some of these of interest to chemical engineers will be found in the plant article on pp. 125-128. Pictured flowsheet on pp. 150-153

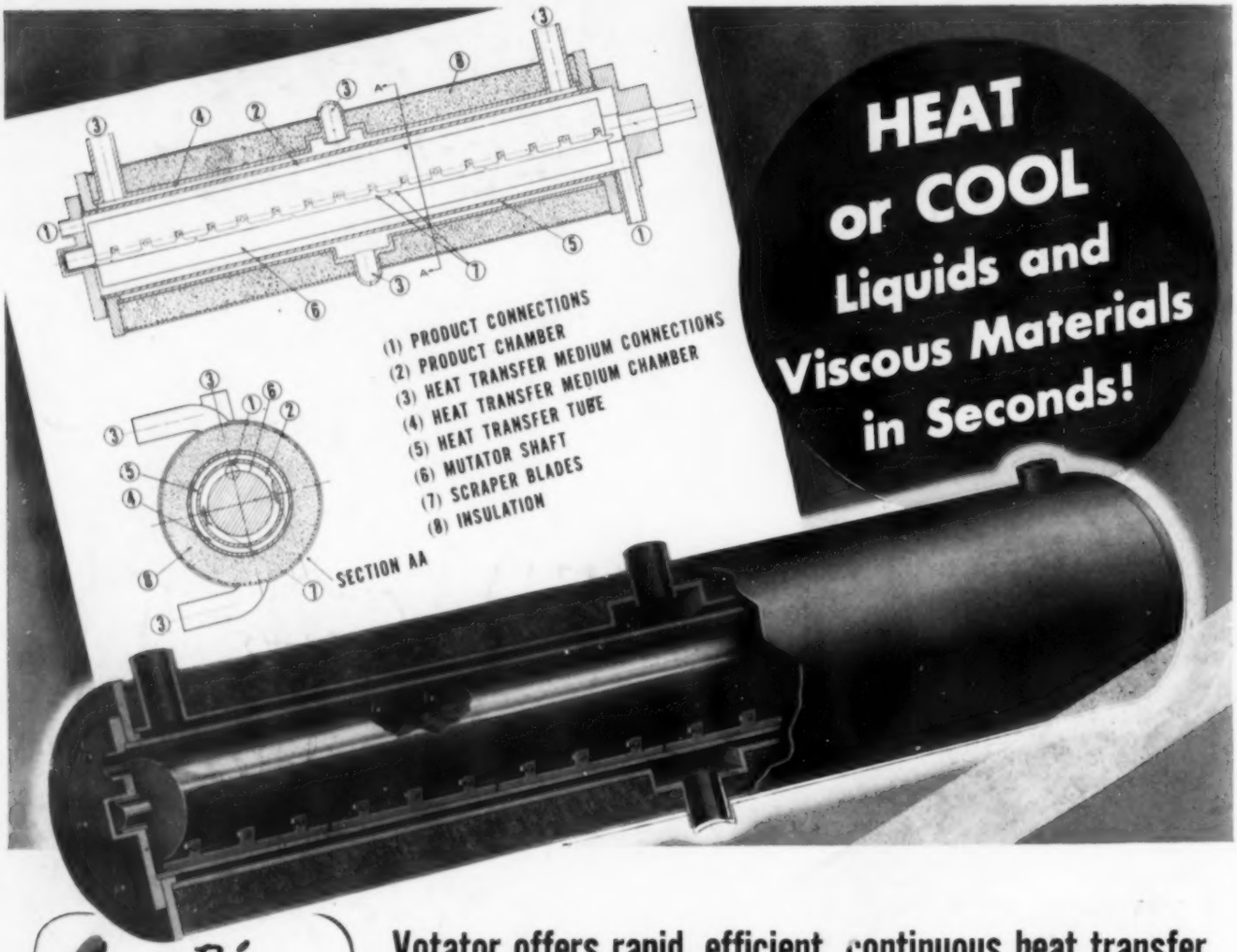
DIFFUSING KNOWLEDGE ABOUT DIFFUSION

This month's special 48-page report interprets and reviews the latest developments in the diffusional unit operations of rectification, absorption, extraction, drying, leaching and dissolving, and gaseous diffusion. Our authors emphasize the part diffusion plays in limiting the rate of completion of these operations. See pp. 77-124

GETTING MORE ALCOHOL FROM PRESENT PLANTS

A resourceful chemical engineer shows how existing facilities in many distilleries can be adapted to increase production without using strategic metals. An all-wood still is one possibility. See pp. 129-131 for others equally challenging.

WASHINGTON NEWS pp 158-159



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Chem & Met

NEXT MONTH

Southward and westward chemical industry steers its course. Stimulated by war demands, more and more new plants are being crowded into the four states of Arkansas, Louisiana, Texas and Oklahoma. The Gulf Coast from New Orleans around to Corpus Christi, with its famous trinity of cheap fuel, salt and sulphur, continues to attract chemical enterprises. But many mineral resources, combined with excellent transportation by rail or water, are also determining factors. *Chem. & Met.*'s managing editor, James A. Lee, will report again in June on the results of his recent trip through this territory for the purpose of visiting plants and interviewing authorities on industrial development.

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CHEMICAL & METALLURGICAL ENGINEERING

ESTABLISHED 1902

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H. F. JOHNSTONE, D. F. OTHMER, ARNOLD WEISSELBERG, E. G. SCHEIBEL, H. R. DUFFEY, J. C. ELGIN, H. B. CALDWELL

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CHEMICAL & METALLURGICAL ENGINEERING

ESTABLISHED 1902 S. D. KIRKPATRICK, *Editor*

MAY, 1942

"Acres of Diamonds"

THERE is the story which was so often told by the late Russell H. Conwell in the famous lecture he called "Acres of Diamonds." It was about an ancient Persian who lived in contentment until a Buddhist priest told him of mythical mines of diamonds where the white sands of a river were saturated with gems of great value. Then Al Hafed became discontented, sold his homestead and spent the remainder of his life in a futile search for this source of unbounded wealth. Finally, discouraged and disappointed, he took his own life when he found that the stranger to whom he had sold his farm had later discovered in the sands of one of its garden streams, literally acres of diamonds. From that old farm came gems that have since decorated the heads of many monarchs. From there came the famous Kohinoor diamond, now among England's crown jewels.

One does not have to ponder long to find the moral of such a tale. We go to great extremes, to faraway places, to search for our fortunes only to find too often that they lie buried in our own backyards!

Today industrial diamonds are almost priceless, but so, too, in a different sense, are the strategic metals and materials so sorely needed to keep our war machine functioning ever faster and faster. Military uses will take all the magnesium, aluminum, nickel, chromium and copper, and most of the zinc and tin for the next two years. A new technique in war-time thrift is therefore becoming a prerequisite to the privilege of staying in business. It is a job that chemical engineers in industry must face and do something about.

William L. Batt, Director of Materials, War Production Board, recently said, "The biggest single source of strategic and scarce metals lies above ground,—i.e., in the materials we are wasting!" Here then is a challenge and an opportunity for every resourceful engineer. The better the man, the better the job he will do. No one in the average industrial organization is better equipped to tackle the problem of salvaging industrial scrap than the engineer who knows what unused equipment is obsolete and can be discarded, who knows what buildings can be demolished and where to turn for other sources of scrap and salvageable materials.

One fairly large company in New Jersey is salvaging more than two tons a day of waste paper, cardboard and old rags. In addition it saves and utilizes old paint pails, 5-gal. tins, empty drums, burlap bags, old grinding wheels and files, barrels and nail kegs. Each of these items goes into its own special container and is collected, carefully checked and sorted. The old adage about "what is worth doing, is worth doing well" certainly applies here. To save a critical metal only to render it useless by mixing it with other materials now falls into the category of crime.

Even though we would like to share in Jesse Jones' optimism about the prospective achievements of our fellow chemical engineers in the synthetic rubber business, we cannot honestly dodge the fact that we are approaching a rubber crisis in this country. We need to salvage every possible pound of old rubber. Not only tires and tubes and hot water bottles and bath mats, but rubber belting, bumpers and gaskets, fire and industrial hose, and mechanical rubber goods of all kinds, must somehow find their way promptly back to the reclaiming plants.

Each industry nowadays has its own peculiar shortages of raw materials. Some of these threaten production more seriously than all the wage-hour and patent and profit controversies we have been making so much noise about. But hanging over all our heads is the vital need for metals, not only to make guns and ships, but, equally important, to make the equipment and machinery required for

the new synthetic rubber and other essential plants. Perhaps, it is not exaggerating too much to think of these once common metals as jewels of great value. If so there are "Acres of Diamonds" under our feet.

THIS MONTH'S REPORT

CHEMICAL ENGINEERS have long recognized the fact that the basis for equipment design and operation was well grounded so far as stoichiometric and equilibrium relations were concerned. In most cases, however, the same certainty has not been attainable in the phase of design which requires a knowledge of the transfer of material between phases. And since material transfer is often the factor which sets the time needed to accomplish a given operation or reaction, choice of equipment size has remained largely empirical. Reasoning has usually stemmed from the results of similar operations or from small-scale testing.

It is only in the last decade that much effort has been applied to right this situation. A relatively small group of men have devoted their efforts to the study of diffusion. Some have developed the mathematical theory. Others have tested the theory and have attempted to set up correlations which can be used in practice. Much remains to be done and readily useable results are still not very numerous. But the work is progressing and chemical engineering will ultimately be benefited considerably.

To interpret the present state of knowledge in several of the major diffusional operations is the purpose of the group of articles that follows in this issue. They are presented here in a special 48-page report—as one of *Chem. & Met's.* long series of reports and reviews of the unit operations of chemical engineering. We commend the report to your attention, either for a quick review of improvements, new developments, and design methods; or as an up-to-the-minute basis for thorough study.

WASHINGTON HIGHLIGHTS

PLANNING even farther ahead is now necessary. Prompt delivery of many raw materials cannot be expected. Materials of construction and for maintenance and repair are difficult to get and advanced ordering helps but little. Improvisation is the keynote. Makeshift engineering becomes a new branch of the profession.

SHORTAGES of material now limit the extent of the war effort. Washington still makes more noise about wages, working hours, profits, patents and other economic factors. But a few people in high places are beginning to realize that none of these, probably not all combined, so seriously limit the magnitude of actual delivery of fighting equipment.

PATENTS will have little value to anyone if radical members of the Senate have their way. Fortunately, it is doubtful whether Congress will go as far as these extremists would like. But it is no longer safe to use patents as a sole basis for industrial security. What they will be worth after the war is any man's guess.

FOREIGN patent deals are all under fire in Washington. Those who would break down the whole patent system are arguing that every such arrangement has given foreign corporations or cartels control of American enterprise. The fact that such exchanges have brought a tremendous amount of useful information and opportunity for aggressive development in the United States is deliberately concealed. The campaign on this subject has a few ardent but very vocal supporters. They have no desire to seek the facts other than to distort them. Their real motive is to attack the patent system. Of course, the campaign is conducted in a costume of patriotic zeal.

RUBBER plans were mismanaged by Jesse Jones, so official Washington thinks. In any event, he is in the dog-house and much of his power is being stripped from him. Thus the New Deal re-establishes its tradition that the Secretary of Commerce is a nice figure-head who is not even permitted to speak influentially for business.

POWER decides the choice between aluminum and paper pulp as offered to Uncle Sam by Canada. There is not enough power to make as much of both as we would like to buy. This is typical of the situation in regard to many things on which difficult and strange decisions are required of both public officials and company executives and engineers.

NO MORATORIUM has been declared on anti-trust actions of the government. War and Navy Department officials can request that actual prosecution of anti-trust cases be delayed by the Department of Justice if it appears that immediate court action might interfere with war effort. But the laws regarding agreements in restraint of trade are still in force and the Department of Justice is very much on the job enforcing them.

CONTRACTS will continue to be readjusted to save the government money. Wherever there is the slightest evidence of an over-generous profit being made on war contracts, the government is going to ask for changes in contractual terms. There is no evidence that comparable readjustments are being authorized when a contractor is losing money. As usual, the business of contracting with Uncle Sam is a one-way street.

TARIFF rates are to be lowered on many goods as the State Department negotiates more trade agreements with Latin American countries. The campaign which Secretary of State Hull has waged so successfully for the past eight years is continuing in discussions with Chile, Uruguay, Peru, Bolivia, and particularly with Mexico.

CONTAINERS to package important chemicals generally take the same preference rating as do other "operating supplies" which are required in the manufacture of the chemicals themselves. This means that A-3, or sometimes much better, priority can be had for drums and other containers needed in essential war enterprises.

CHEM & MET REPORT ON

Diffusional Operations in Chemical Engineering

TO CHEMICAL ENGINEERS, PLANT EXECUTIVES AND PRODUCTION MEN IN PROCESS PLANTS

Although from its title this report may appear to be limited to the diffusional aspects of chemical engineering, it might better be described as a series of briefed-down *Chem. & Met.* reports on several of the most important of the unit operations of chemical engineering, including rectification, drying, absorption, extraction, crystallization, leaching and dissolving. These operations are all classed as diffusional, since in all molecular diffusion plays an important part as the means of transfer of material between phases. In some the rate of mass transfer is the controlling factor in the speed with which the operation can be carried out; in others it is not controlling, but still of interest. Each article attempts to show the extent to which diffusion does control, and how far present knowledge permits rational design. More than this, each article is a short but comprehensive review, stressing both principles and new developments.

CHEMICAL AND METALLURGICAL ENGINEERING · MAY, 1942

Introduction to Diffusional Operations In Chemical Engineering

H. F. JOHNSTONE *Professor of Chemical Engineering, University of Illinois, Urbana, Ill.*

As is often pointed out, chemical processes and operations are limited not only by the equilibrium conditions which determine how far the action can proceed, but also by the rate-determining factors which control to what extent the equilibrium can be approached in a given amount of time. One of the most important of the rate-determinants is diffusional transfer of materials between phases, and since diffusion is a common characteristic of many unit operations, it is often the controlling resistance of the action. When diffusional transfer controls, it fixes the necessary retention time in equipment, and hence the equipment capacity and size.

Despite the fact that diffusion's importance has been recognized for a good many years, it is only quite recently that the study of unit operations from the diffusional standpoint has begun to pay dividends in better understanding of the operations and in new tools for chemical engineering design. Even now our information is far from complete, but the value of the diffusional approach has been demonstrated, and its understanding has facilitated design, even when the necessary coefficients have not been obtained. Sometimes the value is negative, in showing that diffusion is not the limiting resistance. In any event, this symposium will clarify the situation for a cross-sectional group of unit operations* and will assist materially in bringing together the diverse phases of recent developments. Not only diffusion but other aspects also are discussed.—*Editors.*

IN CHEMICAL ENGINEERING the operations most frequently encountered are those in which materials are transferred from one phase to another. Almost any combination of the three states of matter, solid, liquid or gas, might be considered and an example of interdiffusion found in practice. A classification of the diffusional operations on this basis is shown in the table on the opposite page. It is evident from this that any generalizations that might be made concerning diffusion will be applicable to a large number of industrial processes. If the analogy between mass transfer and heat and momentum transfer is included, the fundamental principles of the diffusional processes become even more important.

The reason for this is obvious. In chemical engineering, we are usually concerned with dynamic rather than with static conditions. In continuous operations, a chemical reaction, or a physical change, must be accomplished while the material is actually moving through the equipment. Even in batch operations, it is generally desirable to maintain agitation or contact between the phases at a moving boundary in order to accelerate the interaction. Diffusional operations, in general, are relatively slow. The transfer of material from one phase to another, therefore, requires time. The slower the diffusion the more important it becomes in establishing the size of the equipment, as well as the cost of the operation.

A consideration of where this bottleneck of diffusion may be met and how it may be broken is one of the objects of this series of papers.

During the past decade, there has been considerable increase in the scientific knowledge of the diffusional operations. The realization of the analogy existing between the various operations has resulted in correlations which have been far-reaching. These are based on a theory which has required the use of a number of new terms, not always familiar. Furthermore, some of the industries based on diffusion are among the oldest in existence. It is not surprising, therefore, to find words and terms used which are indefinite and overlap in meaning. In order to avoid confusion, a few of the more common terms used in diffusional operations are defined on page 80.

DIFFUSIONAL OPERATIONS

As shown in the table, with the exception of the simple mixing of gases and liquids, and the dispersion of smokes and fumes, the diffusional operations consist in the transfer of material across a phase boundary. At the actual interface, molecular motion is so rapid that equilibrium is instantaneously established. The entire resistance to the passage of material from one phase to the other, therefore, must lie in the slowness with which the molecules are brought up to the interface on one side and are removed from the interface on the other side. The situation is similar to the transfer of heat through two solids which are in close contact with each other. There is no resistance to heat transfer at the actual interface between the two solids, that is, the temperature of one surface is exactly equal to the temperature of the other, provided, of course, that contact is perfect. There must be a temperature difference, however, from the outside of one solid up to the interface and from the interface to the outside of the other solid in order for heat to flow.

There is one important difference between heat transfer and mass transfer. When two bodies are in thermal equilibrium, the temperature of each is identical. On the other hand, when two phases are in equilibrium, the concentration of molecules is seldom the same in both phases. Thus, the density of saturated steam is far different from that of water with which it is in

* A notable omission from the operations dealt with is humidification which, however, is being treated at length in Edward Simons' current series of articles on cooling tower design.—*Editor.*

equilibrium. Likewise a solute distributed between two liquid solvents is usually found to have entirely different concentrations in each liquid.

There is perhaps one important exception to the rule of instantaneous establishment of equilibrium at the interface. This is in the crystallization of solids from saturated solutions. The fact that molecules must fit into definite positions in the crystal lattice seems to require additional time so that diffusion up to the interface represents only a part of the total resistance in this process.

Film Concept—At a moving boundary, the mechanism of transfer of material up to the interface is not one of simple diffusion. Immediately adjacent to the interface, the fluid is completely stationary but the velocity increases rapidly with distance away from the boundary. If the flow of the bulk of the fluid is turbulent, there is no sharp line of demarcation separating the laminar film from the turbulent core. Furthermore, material must be transported from the core to the film and through the film to the interface. In order to avoid having to take into consideration all of the complicated mechanisms of transport and variations of velocity, it is simpler to use the concept of "effective film thickness," as if the mechanism were one of true diffusion through a strictly stagnant layer. Since the thickness of the film is hypothetical, it is not surprising to find that it varies with quantities which otherwise should have no effect. For example, it has been found to depend on the diffusivity of the substance actually diffusing.

In those operations in which material is passing from one fluid phase to another, an effective film thickness must be considered on each side of the interface. The resistances offered by the two films are seldom the same. Not only may the effective thickness of the films differ, but also the concentration difference which causes the transfer from the bulk of the fluid to the interface, or *vice versa*.

We have already seen that the concentrations in the two phases at the interface are seldom the same. Consequently, there may be a very large diffusion potential (i.e., concentration difference) on one side of the interface and only a small potential on the other side. In this case, other things being equal, the relative importance of the film on the side of the smaller potential, in controlling the transfer rate, will be greater than that on the side of the larger potential. It is for this reason that we speak of one film or the other, or both, as "controlling" in a diffusional operation. In order to accomplish rapid overall transfer, it is obviously desirable to decrease the effective film thickness on the side of the controlling resistance.

In some cases, only one film exists through which material must be transported by diffusion. This is true when one of the phases is a solid, as in leaching, or in adsorption. Likewise, in adiabatic humidification, only the gas film is effective, since the temperature of the interface is the same as that of the bulk of the liquid and there is neither mass nor heat transfer on the liquid side. On the other hand, both films must be considered in dehumidification, because heat must be transferred through the liquid away from the interface. In porous solids, there is, in general, much more resistance to the transfer of material through the capillaries and interstices to the surface of the particle than through the relatively thin film outside of the particle. Actually, the transfer inside of the pores is not always by diffusion. In the drying of porous solids, for example, it has been shown that liquid is generally transported to the surface by capillary action.[2]

Rate of Diffusion—In all cases in which diffusion is the means of transferring material, the rate of transfer may be stated by the simple equation:

$$dW/dt = KA\,\Delta C \qquad (1)$$

Here dW/dt is the rate of mass transfer, expressed as a differential quantity since the other terms may vary from point to point; K is the transfer coefficient as defined in the table of definitions on page 80; A is the area through which the diffusion is taking place; and ΔC is the concentration difference causing the diffusion. Since the concentration at the interface is unknown, it is common to use an overall concentration difference and ΔC

Classification of Diffusional Operations

Process	Class		Type of Diffusion	Relative Importance of Diffusion in Controlling Rate	Remarks
	Diffusing From	Diffusing To			
Unsteady state mixing of gases in closed containers	Gas	Gas	Molecular diffusion	Entirely controls	Very slow unless thermal currents or other agitation
Dispersion of smokes and fumes	Gas	Gas	Eddy diffusion	May be controlling, depends on atmospheric and physiographic conditions	Scale of eddies varies tremendously
Absorption of gases, Dehumidification	Gas	Liquid	Eddy diffusion in core and mostly molecular diffusion through layers at interface	Overall diffusion rate controls the rate of the entire process	For absorption, diffusion in either gas or liquid films, or both, may be important depending on solubility of gas
Adsorption of gases	Gas	Solid	Mostly molecular diffusion outside of solid; entirely molecular inside pores	Diffusion may control if activity of adsorbent is high	Most adsorbents show selectivity for specific gases
Contact catalysis, Reactions between solids and gases	Gas	Solid	Same as above	Diffusion controls in some cases (eg., oxidation of SO_2), but not in others	Influence of temperature on overall reaction rate is usually small when diffusion controls
Vaporization, Humidification	Liquid	Gas	Eddy diffusion in turbulent core; mostly molecular diffusion in gas film	Controls if adequate heat transfer to supply latent heat of vaporization	In general, only diffusion through the gas is important
Desorption, Steam distillation, Stripping	Liquid	Gas	Same as above	Overall diffusion rate controls	Diffusion in gas usually the most important, except when dealing with very low concentrations of gases, as in deaeration
Distillation	Liquid	Gas	Same as above	Controls entirely	Resistance to transfer in vapor phase is probably always major factor. Counter-diffusion apparently does not cause any greater resistance than diffusion through stagnant inert gas
Solvent extraction	Liquid	Liquid	Probably always molecular	Entirely controls in continuous equipment; with mixers and settlers, rate of separation may control	Both films are important
Crystallization	Liquid	Solid	Mostly molecular	Sometimes diffusion controls, but in general rate of crystal growth is important	Crystal habit is important
Drying	Solid	Gas	Usually capillary action inside solids; sometimes molecular diffusion of vapor in pores	Entirely controls if heat transfer is sufficient	Very few solids are sufficiently homogeneous for diffusion laws to apply in falling rate period
Sublimation	Solid	Gas	Molecular diffusion	Same as above	
Extraction, Leaching, Dissolving, Washing	Solid	Liquid	Dialysis through cell walls, molecular diffusion in pores	Diffusion may control entirely if material is tightly held by inert solid	Porosity of solid is important; for small porous particles equilibrium appears to be reached rapidly
Heat treatment of metals and other solids, Devitrification	Solid	Solid	Molecular diffusion through crystal lattice	Diffusion may control entirely	Very slow process

then becomes the difference between the actual concentration of the solute in one phase, and that which would be in equilibrium with the solute concentration in the other phase. The concentration may be expressed in terms of weight (or moles) of solute per unit volume of either phase, and the absolute value of the concentration difference, or diffusion potential, depends on which phase is chosen as the basis of the expression. Since the actual rate of diffusion must be the same regardless of how the concentration is expressed, the value of the overall transfer coefficient depends on the manner in which the concentration difference is expressed. Thus, we find it common to use a subscript on the overall transfer coefficient, such as K_1 and K_2 (or K_l and K_g), indicating the phase in which the concentrations are expressed.

As shown by Equation (1), the factors which influence the rate of transfer are: (1) diffusion potential, or concentration difference, (2) the value of the overall transfer coefficient itself, and (3) the interfacial area. It is now in order to consider, in a general way, how these factors are influenced by various operating conditions and how they may be estimated so that the equation can be used for design purposes.

Diffusion Potential—One of the terms that determine the diffusion potential is readily known, viz., the actual concentration of the material in the bulk of the fluid. The other term is the solute concentration which would be in equilibrium with the bulk of the other phase. When the two are equal, no diffusion can take place. In a continuous operation, there may be points in the apparatus in which the potential is large but, if at any one point it becomes small, or vanishes because the two phases approach equilibrium, the size of the equipment required becomes infinitely large. This is the basis of the rule that equilibrium can not be reached at any point in a continuous operation depending on diffusion. The equilibrium relationship, therefore, is of great importance in determining the size of the equipment required.

There are many types of equilibrium relationships and it is not always possible to foretell what type a particular system fits without actually having the experimental data. Fortunately, some of the laws available for ideal solutions are applicable over a considerable range of concentration. The most important of these is the law of Linear Distribution, i.e., the concentration in one phase is *proportional* to that in the other. There are many examples of this which may be found for the distribution of solutes between all types of phases. The most familiar is Henry's law for gases. This is applicable to absorption calculations and has been found to hold for the solubility at low pressures of many gases which do not form compounds with the solvent. A special case of Henry's law which is often applicable to a different range of concentration is Raoult's law. The law of Linear Distribution also holds for many solutes distributed between two immiscible liquids.

It is interesting to note that in the extracting of solids, such as by leaching and washing, there is frequently linear distribution between the amount of solute held in the pores of the solid and the amount present in the clear solution. The reason for this is that the amount of solution left in the solid after draining is often independent of the concentration of the solution. Consequently, the amount of solute in the drained solids is proportional to the amount in the clear solution, if the concentration of the solution is uniform. The ratio of the amount of solute left in the solid to that in the clear solution would depend, of course, on the method of solution removal used, such as thickening, filtering, or centrifuging. This important principle will emphasize the analogy between extraction and absorption and is the basis of a common method of calculation to be described below which is applicable when the law of Linear Distribution holds.

Overall Transfer Coefficient—The overall transfer coefficient K may be

Definitions

Absorption—Removal of one or more soluble components of a gaseous mixture from an inert gas by dissolving in a liquid solvent. The term is distinguished from adsorption which refers to the removal of a component from a gas or liquid mixture by means of a porous solid with which it combines chemically or physically.

Continuous Countercurrent Decantation—The washing of a solid by a series of mixers and thickeners arranged for counterflow of solids and solution.

Diffusion—The spontaneous transfer of a component of a fluid mixture from one point in the fluid to another, without respect to fluid flow. *Molecular* diffusion refers to the net transfer of materials caused by the normal Brownian movement of the molecules, while *eddy* diffusion refers to the mixing of fluids caused by eddies or turbulence. In both types, the net transfer of material is proportional to the difference in concentration at the two points. The term "diffusion" has also been used in the sense of removing a soluble material from an insoluble residue, such as sugar from beet pulp, or tanning extract from wood. Undoubtedly, the mechanism in this case is by dialysis through the cell walls and diffusion through the capillaries. The operation is an example of the generalized type of extraction.

Diffusivity or ***Diffusion Coefficient***—A numerical coefficient representing the tendency of a component of a system to diffuse, analogous to heat conductivity. It represents the quantity which will diffuse across unit area in unit time with unit volume concentration gradient. The dimensions, therefore, are $(\text{length})^2/\text{time}$.

Dissolving—The process of dissolution of a completely soluble material, either liquid or solid, in a solvent.

Effective Film Thickness—The thickness of a film having the same resistance as the combined resistances of the core and laminar layer at a moving interface to the transfer of mass or heat.

Extraction—The general term for transferring material from an inert solid or liquid to a solvent.

H.T.U.—The height of packing required for one transfer unit. This quantity is proportional to the mass velocity divided by the mass transfer coefficient.

Leaching—The removal of a readily soluble material from an inert solid; usually refers to extraction with water.

Lixiviation—An old term meaning essentially the same as leaching. According to general usage, leaching and lixiviation refer to the removal of materials which are very soluble, while extraction refers to the removal of a material which is quite firmly held by the insoluble residue.

Number of Transfer Units—A measurement of the difficulty of a transfer operation expressed mathematically as an integral of approximately the ratio of the differential quantity transferred, to the diffusion potential. For diffusion in one direction it is given by the equation

$$n = \int_{y_2}^{y_1} \frac{(1-y)_f\, dy}{(1-y)\,(y-y^*)}$$

where y is the mole fraction of the solute in the phase from which diffusing is taking place, y^* is the equilibrium value for the other phase, and $(1-y)_f$ is the log mean of $1-y$ and $1-y^*$.

Percolation, or ***Percolation Filtering***—The extraction of a material by a liquid solvent from an inert solid (or adsorption from solution by an inert solid) in which the solid is stationary and the solvent flow is continuous.

Rectification—The separation of a liquid mixture by distillation in which a part of the condensate is returned as reflux for contact with the vapors.

Transfer Coefficient—A numerical coefficient indicating the rate of transfer in diffusional processes per unit interfacial area and unit diffusion potential (concentration or pressure). When the interfacial area is not known, a volume transfer coefficient may be used, representing the rate per unit volume of packing and unit concentration difference.

Washing—In general, refers to the removal of a small amount of dissolved material from an insoluble liquid or solid by displacement with fresh solvent.

considered as the reciprocal of the resistance to mass transfer from the body of one phase to that of the other. If two films exist at the interface and the resistance of both is appreciable, the overall resistance is actually composed of two resistances in series and is equal to the sum of the resistances of the individual films. In terms of the individual film transfer coefficients, therefore, the overall coefficient may be represented by

$$1/K_1 = 1/k_1 + m/k_2 \qquad (2)$$

The constant m is necessary because the units in which the individual coefficients, k_1 and k_2, are expressed are not the same, owing to the difference in the manner of expressing concentration in the two films, as already explained. Actually, m represents the ratio between the equilibrium concentrations in the two phases. Unless the law of Linear Distribution holds, m may not be a constant. The relationship between the two overall coefficients expressed in the terms of the concentration in the two phases is as follows:

$$mK_1 = K_2 \qquad (3)$$

We shall now consider the factors which affect the individual film coefficients, as these must in turn affect the overall transfer coefficient. The film coefficient is approximately proportional to the diffusivity of the solute and inversely proportional to the effective film thickness. When the concentration of the diffusing material is high, it is known that another factor must be considered, viz., the actual concentration of the solvent, or inert material. For most cases this may be neglected, but for certain cases of absorption and condensation it may become important.

Information on the absolute value of the diffusivity of solutes in gases is in fairly good shape but there is much to be learned before any general correlation can be made for diffusivities in liquids. For gases, the kinetic theory serves as a basis for many theoretical calculations and several equations have been derived by which the diffusivity may be calculated from constants which are known, or can be approximated. There are considerable experimental data available for the diffusivities in gas systems. A few years ago the entire subject was surveyed by Gilliland[10] who recommended the following equation as the most suitable for calculating diffusivities for systems for which the data are not available:

$$D = 0.0043 \times \frac{T^{3/2}}{P(V_a^{1/3} + V_b^{1/3})^2}\sqrt{\frac{1}{M_a} + \frac{1}{M_b}} \qquad (4)$$

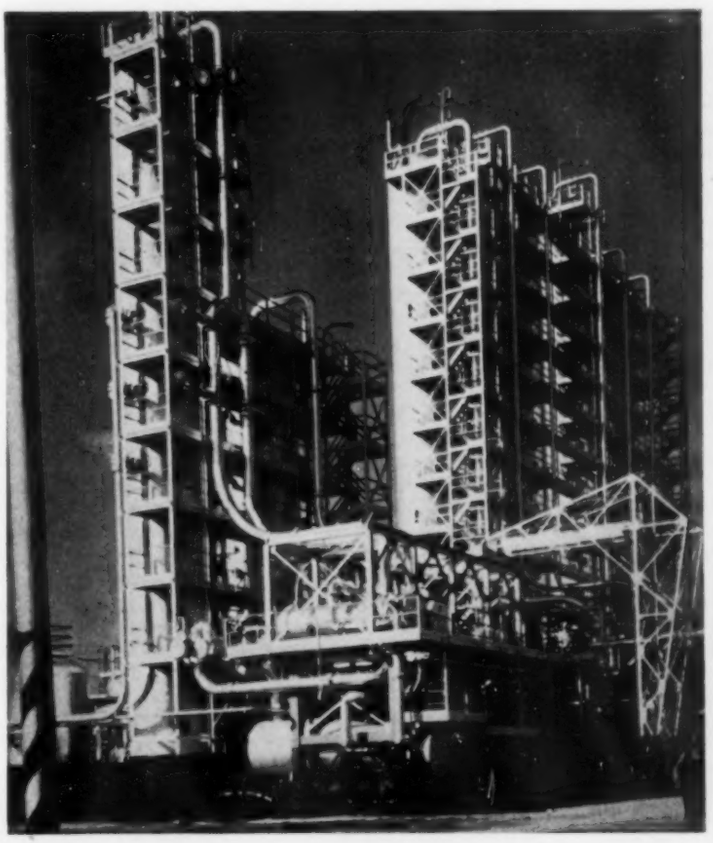
In this equation, the diffusivity D is given in (cm.)^2 per sec.; P is the total pressure in atmospheres; T is the absolute temperature in deg. $K.$; M_a and M_b are the molecular weights of the two gases; and V_a and V_b are the molecular volumes. The values of V_a and V_b are obtained by using the law of additive volumes, with the rules and values given by Le Bas. These are given in Gilliland's paper and are also published in many text books. It is important to note that the diffusivity is inversely proportional to the pressure and directly proportional to the square root of the sum of the reciprocals of the molecular weights of the gases.

Diffusivities in liquids are much lower than those in gases. Application of the kinetic theory to prediction of the coefficient has only been partially successful due to the abnormal effects caused by the association or bonding of both solvent and solute molecules. Data are available in the International Critical Tables for the diffusivities of a number of dissolved gases and other solutes in water, and for a few materials in organic solvents. In the absence of further information, it is suggested that data for substances as nearly as possible like the solute and solvent in question be used. Fortunately, liquid film diffusion coefficients for simple solutes do not show the great range in values shown by gas diffusion coefficients.

Even if diffusivities were known with great accuracy the individual film coefficients could not be calculated without knowing the effective film thickness. This is a much more complicated proposition. The most important factors affecting the film thickness are the interfacial velocities of the fluids and the degree of turbulence caused by the shape of the interface. For fluids in turbulent flow, the thickness of the film is approximately proportional to $V^{-0.8}$, where V is the interfacial velocity. The thickness is also affected by the properties of the fluid and of the material diffusing. It is approximately proportional to the square root of the viscosity of the fluid and of the diffusivity of the solute, and inversely proportional to the square root of the density of the fluid.

Interfacial Area—The area of the interface across which diffusion takes place is another quantity on which there is usually little exact information available. It is well known that in a packed tower, for instance, the area of the packing is by no means the same as the area of the interface. This is because of the channeling of one or both fluids, and the existence of pockets in which there can be no flow. Certain types of streamline packing, of course, have more effective area per unit volume than others. There must also be a balance between the area available and other characteristics of the packing, such as the pressure drop and flooding velocity. Because of lack of information on the absolute value of A, it is common to combine the area with K into a volume transfer coefficient Ka, where a is the actual interfacial area per unit volume of packing. A few experimental values

Diffusion is a controlling factor in rectification



of Ka for gas absorption on various types of packing are available in the literature.[15] Individual film coefficients for various packings have been determined for a few gases.[17] Only recently, information on film coefficients for liquid-liquid extraction have begun to appear.[1, 4, 7, 12]

The Theoretical Plate or Stage—When the rate of transfer of a material between two phases is entirely unknown, it is sometimes advantageous to predict the difficulty of separation by an entirely different concept. In this, we assume that the two phases are brought to actual equilibrium with each other by thorough mixing, and then are allowed to separate and flow in their respective directions, either countercurrently or in parallel. The most familiar application of this idea is in the McCabe-Thiele diagram for distillation.[20] Here it is possible to predict the number of theoretical plates required for a given separation by a graphical method, using the equilibrium between liquid and vapor and a specified operating ratio of vapor to liquid. In order to know the actual size of the distillation column required, it is necessary to know how efficient the various plates are in bringing the two streams to equilibrium and also to have information on what vapor velocity is allowable.

Application of this concept to a plate column is somewhat more evident than it is to a packed column. If we conceive of a section of packing as being required to bring about equilibrium between the phases, we can still use the same concept of a theoretical plate and determine experimentally the height equivalent to the theoretical plate, or H.E.T.P. for the packing.

The concept of the theoretical plate, or stage, is applicable to all types of diffusional operations. The literature contains a number of valuable papers describing the use of the method for the graphical treatment of problems on absorption,[15] humidification,[18] liquid-liquid extraction,[6, 12, 14] and the leaching and extraction of solids.[8] In these operations there is one complication which does not exist in distillation calculations, namely, it is usually incorrect to assume that the operating line is a straight line. The reason for this is that in most diffusional operations the ratio of the two phases is not constant for all stages, as it is in distillation. This difficulty is avoided, however, by the use of triangular diagrams, or of rectangular diagrams of the Merkel, or Ponchon type.[12, 13]

When the operation consists of the separation of two or more solutes from an inert solvent by transfer to another phase, these methods of calculation, at best, are only approximations. The analogy which can be set up between certain diffusional operations, such as extraction and distillation, however, has been extremely helpful. Thus, in solvent extraction, the benefit to be derived from returning a reflux stream in countercurrent operation is immediately apparent by a calculation of this type.[9, 12, 14]

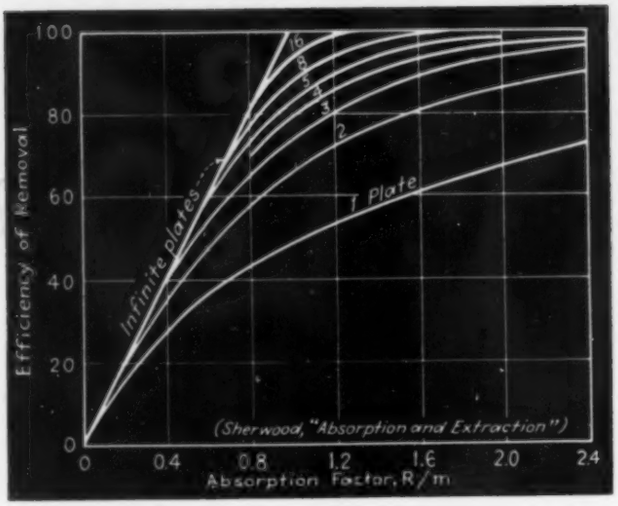


Fig. 1—Performance efficiency of multi-stage countercurrent diffusional operation for case of linear distribution of solute between phases (after Sherwood)

The Kremser Formula—The concept of the theoretical stage, or plate, is especially valuable when the law of Linear Distribution holds for the equilibrium between the two phases. For this case, Kremser has derived an algebraic expression relating the composition of the streams entering and leaving the equipment to the number of stages.[11, 19] For the important case of the countercurrent absorption of gas, where the concentrations of the solute in the gas and liquid are low so that the streams are essentially constant, the formula becomes

$$\frac{Y_1 - Y_0}{Y_1 - mX_0} = \frac{\left(\frac{R}{m}\right)^{n+1} - \frac{R}{m}}{\left(\frac{R}{m}\right)^{n+1} - 1} \qquad (5)$$

Here Y_1 and Y_0 are the gas concentrations entering and leaving the absorber; X_0 is the concentration of solute in the solvent entering the absorber; m is the constant distribution ratio of the solute between the gas and liquid at equilibrium; R is the ratio of the liquid velocity to the gas velocity; and n is the number of theoretical plates. The left side of the equation represents the ratio of the actual change in gas composition to the change which would occur if the gas leaving were in equilibrium with the solvent entering the absorber. If fresh solvent is used, containing no solute, X_0 is zero, and the ratio becomes the actual fraction of the gas recovered, and represents the efficiency of the column. In Fig. 1 is shown a plot of the Kremser formula which indicates the effect of the ratio of liquid to gas, and the number of theoretical plates, on the percentage recovery for a given value of the distribution coefficient m, and when fresh solvent, free from solute, is sent to the absorption tower.

Exactly the same type of formula may be derived for a countercurrent extraction, or washing system, such as a series of mixers and settlers. Let B represent the ratio of solvent in the overflow, to solvent in the underflow from each thickener. Then, assuming that this ratio remains constant regardless of composition of the solution, and pure solvent is sent to the last stage, the fraction of solute recovered is given by a formula identical with Equation (5), except that B replaces R/m.

The Transfer Unit—An idea somewhat similar to the theoretical plate, but more logically applied to packed columns, was suggested several years ago by Chilton and Colburn.[3] In this, the difficulty of a transfer operation is expressed in terms of the concentration change to be effected in either fluid stream, and of the driving force. This quantity is defined as "the number of transfer units." The equation given in the table of definitions on page 80 defines the quantity mathematically for diffusion in one direction, such as in absorption and extraction. For equal molar counter-diffusion, as in distillation—or when y is small compared to unity—the number of transfer units is given by the formula

$$n = \int_{y_1}^{y_2} \frac{dy}{y - y^*} \qquad (6)$$

Here, y represents the mole fraction of the solute being separated, the subscripts 1 and 2 referring to the terminal conditions. In the cases where Henry's law or other similar Linear Distribution laws hold, it may be shown that

$$y^* = m\,(y - y_2)/R \qquad (7)$$

Here m is again the equilibrium distribution constant and R is the ratio

of extracting (liquid) phase to extracted (vapor) phase. Substitution of Equation (7) into Equation (6) results in an equation which can be directly integrated. A plot of this integral is given in Fig. 2.[5] This figure is somewhat similar to Fig. 1. It is useful for finding directly the number of transfer units required for many cases of absorption and extraction, for any ratio of entering to exit solute composition, and for different values of m/R. Colburn[6] has recently extended the usefulness of the transfer unit concept by obtaining similar graphs for cases in which the Linear Distribution law does not hold and for variable values of R.

Having determined the number of transfer units, it is only necessary to multiply this quantity by the height of a transfer unit (H.T.U.) in order to find the total height of the packing required to do a given job. The H.T.U. is actually a measurement of the resistance to transfer and as such is made up of the two individual resistances of the individual films. The relationship between the overall H.T.U. expressed in terms of the gas film and the overall mass transfer coefficient $K_G a$, on the same basis is

$$(\text{H.T.U.})_{OG} = \frac{G}{K_G a P M_B} \qquad (8)$$

where G is the mass rate of flow, P is the total pressure and M_B is the molecular weight of the inert gas, all in consistent units.

Colburn has shown that the overall value of the H.T.U. (designated as $(\text{H.T.U.})_{OG}$, when the number of transfer units is calculated from the change in concentration in the gas phase) is given by the equation

$$(\text{H.T.U.})_{OG} = (\text{H.T.U.})_G + (\text{H.T.U.})_L(m/R) \qquad (9)$$

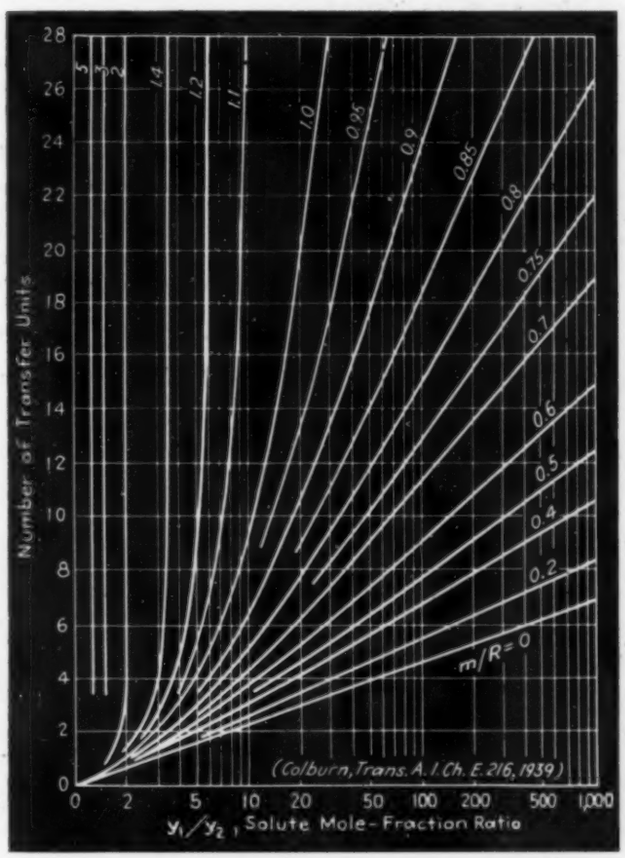
The remarkable feature of Equation (9) is that over a very wide range in operating conditions none of the terms in parentheses varies appreciably. Thus, the value of the equilibrium ratio m, or of the ratio of flow of the two phases R, may vary a thousand fold in practice but the term m/R is practically constant for any given type of problem. For the economic optimum, Colburn finds that m/R scarcely varies outside of the limits from 0.5 to 0.8 for absorption, and 1.5 to 2 for stripping. Likewise, the values of the individual H.T.U.'s do not vary greatly from one solute to another, and are only slightly affected by the velocities of the phases. Values of the individual and overall H.T.U. for both absorption and liquid-liquid extraction on a number of commercial tower packings are given in Colburn's first paper.[5]

THEORY AND PRACTICE

The greatest value of the theory of diffusional operations lies in the picture which it presents for the mechanism by which the transfer takes place, and in the opportunity for drawing analogies and comparisons between the various operations. Few people would claim the theory could surplant practical experience in the design and operation of new equipment. On the other hand, if experimental values for a given set of conditions are known, the theory can be used with reliance to predict the effect of changing one or more conditions over a short range. It is seldom that a complete design can be made without some sort of approximation of this kind. Not until a great deal more information on the subject is available can we expect to make absolute calculations for design and operating purposes.

The author believes that the full significance of the generalizations underlying the diffusional operations has only recently been realized. Considerable work remains to be done in evaluating rate coefficients, especially in liquid-liquid extraction and in the extraction of solids. Information is needed on plate and stage efficiency for distillation and other operations, both for binary and multi-component systems. As these become available there seems to be little doubt that the development of new equipment and new processes will be rapid.

Fig. 2—Number of transfer units required for absorption or extraction operations (after Colburn)



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Distillation Practices and Methods of Calculation

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Professor of Chemical Engineering, Polytechnic Institute of Brooklyn

In hundreds of processes, from gin manufacture to petroleum refining, distillation plays a major role. It is one of the most important tools of the chemical engineer. In what he has called a "Rectification Review" Professor Othmer brings *Chem. & Met.* readers up-to-date on one of the oldest unit operations.—*Editors.*

DISTILLATION is associated by the man in the street with the expensive liquid going into a highball, and vaguely—in recent years—with gasoline and lubricating oils for the family car. "Fractionation," stemming from batch distillation and loosely used, is concerned with many other unit operations: crystallization, size separation, etc. "Rectification" also refers to other ideas, e.g., in electrical engineering it is conversion of a.c. to d.c. "Rectify" means the correcting of an error, or making something better.

In the usual case, rectification is a tool of the process industries. Occasionally our man on the street meets rectification in everyday equipment. One example is the oil rectifier used on an automobile engine to eliminate volatile materials from the crankcase. Another is in the familiar gas refrigerator, in which a small rectifying tower concentrates the ammonia from its aqueous mixture, used as a refrigerant by the absorption process.

The simple operation of distillation is not related to diffusion in any important sense. It is the vaporization of volatile materials, usually to separate one from another. The use of the word "distillation" as opposed to "evaporation" is one of habit rather than of logic. Thus, we talk about evaporators for making "distilled" water; and, in general, the term "distilled" and "distilled product" refers to an evaporation wherein a volatile material is the desired one. "Evaporators" are used when the residue is desired. This convention, while usual, breaks down occasionally.

Simply, a rectifying column is a device for accomplishing successive vaporizations and condensations by mutual heat interchange, to take advantage in each of the relatively greater volatility of one of the components. Thermodynamically, the only energy used is the amount equivalent to the heat of solution or chemical combination. This is almost always very small—hence the thermodynamic efficiency is always low.

EQUILIBRIUM Vs. DIFFUSION

Looking at it from another viewpoint, the rectifying column is a device for obtaining equilibrium between a vapor phase and a liquid phase, and repeating the operation many times. Herein diffusion is the physical mechanism by which equilibria are reached; and the driving force—the difference in concentration—strives to obtain equilibrium many times successively.

"Equilibrium" is static, "diffusion" dynamic. They are the antithetical concepts providing our understanding of what takes place in rectification.

The conception of molecular action between two phases has long been based on the presumption that between these is an interface, across which transfer of material takes place practically without hindrance. (The author, years ago, made an elaborate attempt to measure the driving forces across the interface, probably in the neighborhood of 0.001 mm. of Hg pressure, or 0.00005 deg. C. While it was possible to develop instruments sensitive enough to measure these values, it was not possible to control them in the microscopic thickness of the interface itself.) Thus, the condensation of the less volatile component and consequent re-evaporation of the more volatile, takes place almost instantaneously. This is in accord with the recognized fact that a pure liquid seeks equilibrium almost explosively under the conditions of pressure prevailing as, for example, the flash from the superheated water issuing from a steam trap.

Static films are adjacent to the interface in each phase. While there is little direct evidence from the senses to prove this theory, the considerable indirect evidence of many experimenters substantiates it. The movement of molecules of the more volatile material, *A*, through the liquid film on one side toward the interface, and through the vapor film on the other side, away from the interface and into the vapor stream, is assumed to be due to differences of concentration acting as driving forces. (The less volatile material, *B*, is moving similarly but in an opposite direction.) The motivating force in the liquid film is the partial pressure of *A*, which causes molecules of *A* to migrate through the film toward the interface, because of a lower concentration (pressure) there. Some of the molecules of *A* evaporate into the vapor and diffuse through the gas film to the body of the vapor, where there is a still lower vapor pressure of *A*. In the gas film, another driving force is the partial pressure difference of *B*, which difference of partial pressure causes molecules of *B* to migrate to the interface where they condense and give up an amount of heat equal to that required for the evaporation of the corresponding molecules of *A* which have reached the interface by diffusion through the liquid film. The vaporization of some of *A* leaves the liquid leaner in the more volatile compound. This vaporization enriches the vapor stream as does also the condensation of some of the less volatile component B. The processes are concomitant and are assumed to balance. The rate of this transfer would be indicated by relations similar to the law of heat transfer, with the value of the rates in this case dependent upon the amount of material transferred through unit area in unit time, which is caused by unit of driving force. The algebraic formula is another application of Ohm's Law. (The amount of anything passed or done is always proportional to the driving force or interest and affected adversely by resistance or opposition.)

Consideration of the distilling column (a machine for *diffusion*) is usually based on studies of equilibria. Diffusion is controlling, however; and the kinetic factors governing it allow the equilibrium conditions to be reached. Measurements of the rate of diffusion have usually been crude and in terms of equilibria and the efficiency of contacting of the two phases.

METHODS OF CALCULATION

General—Any attempt to review the theory and calculations of rectification will be a very brief review of the writings of many men. A bibliography would list an army—the leaders: Baker, Brown, Carey, Chilton, Colburn, Dodge, Fenske, Furnas, Gilliland, Hunter, Jenny, Keyes, Kirshbaum, Lewis, McCabe, Murphree, Nash, Peters, Ponchon, Savarit, Sherwood, Thiele, Underwood. [And Othmer—*Ed.*] This group is not complete, but these names keep recurring; and it is impossible to evaluate their individual work here.

Much of the theory developed for the separation of binary, ternary and multicomponent mixtures may be regarded as a help in understanding what takes place rather than as a direct aid in design. Even a list of *all* of the factors involved cannot as yet be made; the necessary physical data for the materials handled—as well as the correct temperatures at which to consider such values—are often unknown and incalculable. The methods of taking into account the known physical data may be unavailable or exceedingly

tedious and then only rough because of the necessity of many simplifying assumptions. There has been real progress, often empirical, in attempts to predict what happens in a rectification—slow trudging and occasional spurts, these hundreds of years.

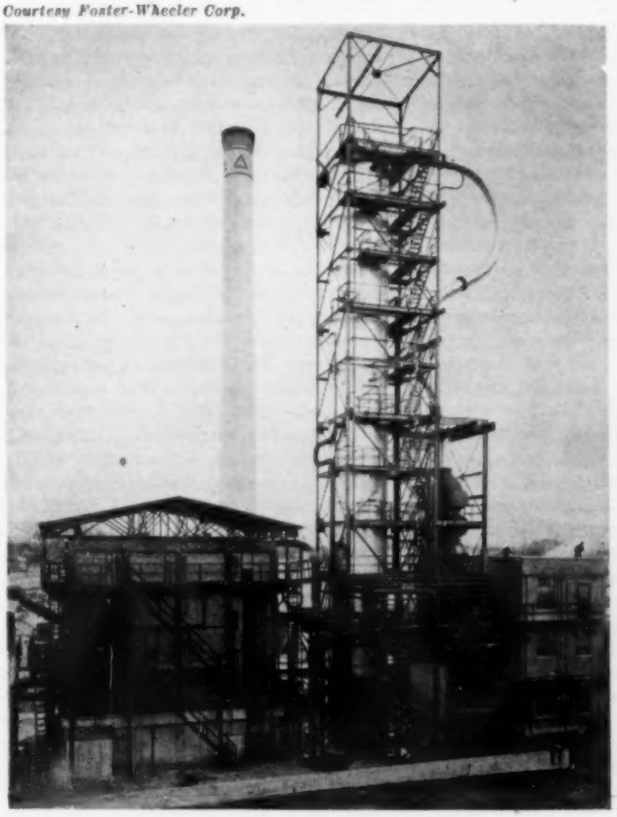
Reflux—Rectification was developed from an appreciation of reflux although not its understanding, some hundreds of years ago. The return of separated material back to the separator once it had been refined did, however, seem absurd. (Even an otherwise brilliant chemist said not so long ago, "What skill hath separated, let no fool put together again.") A simple heat balance shows the necessity, however. Alcoholic vapors entering the column from the distillation of a fermented mash might have 1 lb. of water for each pound of alcohol. At the top of the column, the vapors might be only one-twentieth water. The water entering the column must be condensed out of the vapors as the only method of separation. For each pound of alcohol entering the column and leaving the system, almost 1 lb. of water would, therefore, have to be condensed. This can only be done by the condensation of alcoholic vapors in the condenser and return of this at the top. The condensate liquid flowing back washes the vapors for the removal of water by condensation, and thus enriches or rectifies them. The latent heat per pound of water is about 2¾ times that of alcohol; so about 2¾ lb. of alcohol must be condensed and returned as the least amount of reflux wash which could hold down the pound of water vapor by condensation—with consequent re-evaporation of the alcohol. Nothing less would serve to remove the water's vaporous heat, condense the water and cause it to pass back to the still pot; in practice, somewhat more reflux is required.

Effect of Films on Diffusion—In a bubble cap—or perforated plate-column—a bubble of vapor (1) forms, (2) rises through the wash liquid on the plate, (3) creates a foam at the liquid surface and passes through it, and (4) breaks to give a spray of liquid droplets in the vapor space. In each of these four steps, diffusion is taking place through the two films, tending to bring to equilibrium the two phases and to cause the condensation-evaporation that makes up rectification. There have been discussions regarding which stage is most important, so that design of equipment might emphasize that stage. With the diffusion of less volatile material through a vapor film to the bubble boundary, and thence through the liquid film and the reverse diffusion, there is the usual two-film mechanism. Some feel that in the overall operation of the bubble-cap plate the vapor film controls; i.e., the resistance to diffusion on the vapor side is so large by comparison that the resistance of the liquid film makes little difference. (Thus, one series of experiments showed that narrow slots and adequate submergence gives increased efficiency, as do also higher jet velocities of the vapors, up to a point where the liquid is blown away from the cap rather than being traversed by the vapor.)

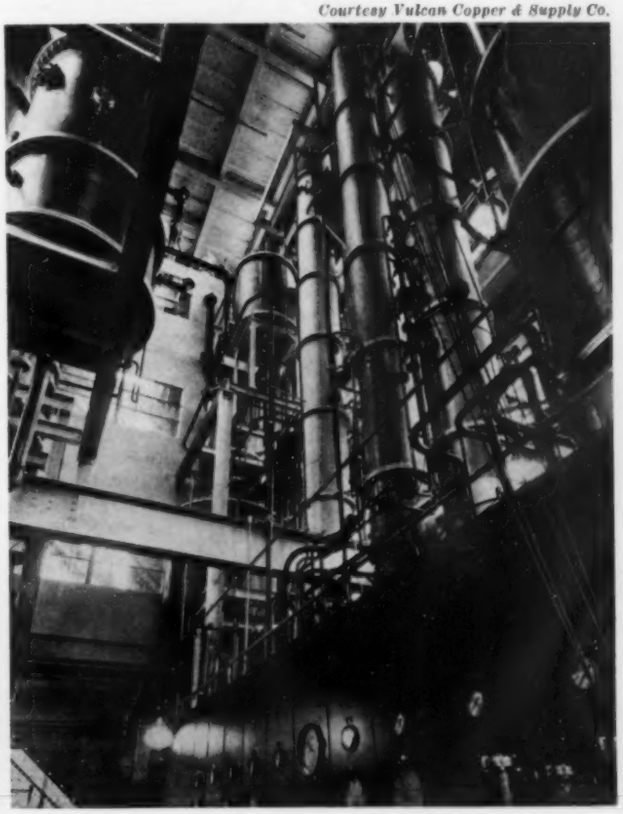
In a packed distilling column where there is a thin film of liquid covering the packing shapes and giving an interface with the vapors rising, it has been shown that at least in some cases the major resistance to material transfer or diffusion is in the liquid film. While it has been noted that in one case the performance of a packed column was affected only slightly by the size or type of packing, the reverse has usually been claimed.

The mechanical carry-over in the vapor stream of liquid from one plate to the next higher plate (entrainment) has been much discussed in its relation to the lowering of column efficiency. In fact, the usual formula for maximum allowable vapor velocities, and hence capacities of columns, was developed with the idea of preventing such entrainment. Diffusion takes place through *inside* liquid and *outside* vapor films of the droplets of the carry-over, the same as through the *outside* liquid and *inside* vapor films of the vapor bubbles. This affects efficiency in a reverse manner to the mass carry-over, adding thereto. The conclusion reached is that under most conditions entrainment has only a very slight net effect on performance of a bubble cap column. (The formula for allowable vapor velocity is still used, with em-

Outdoor distilling unit for separation of petroleum fractions
Courtesy Foster-Wheeler Corp.



Inside installation for solvent distillation and recovery
Courtesy Vulcan Copper & Supply Co.



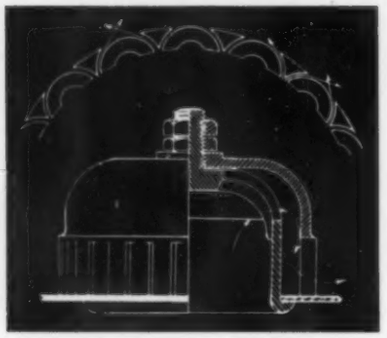


Fig. 1—Vulcan cross-tangential bubble cap. Drawing shows paths of vapor streams

pirical constants which have been experimentally evaluated. Possibly one based on another concept of optimum capacity should be developed.)

The variables controlling diffusion are many and are due to the particular dimensions and arrangement of every part of each individual rectifying column used, the particular concentrations and temperatures of the vapor and liquid streams at every point in the column, and of course on such physical properties as latent heats, specific heats, heats of solution, liquid and vapor viscosities, densities, and surface tensions. Since the physical properties vary throughout the range of concentrations and temperatures in a column, it follows that at every point the conditions affecting diffusion would have to be individually considered.

Theoretical Plates—It is therefore plain why the difficulties of separating these variables have led, in the usual case, to the complete neglect of these individual physical factors controlling material transfer or diffusion, and the "lumping" of their effect into overall efficiencies of what would take place in unitary parts of the column *if* every molecule of vapor were able to come to equilibrium with every molecule of liquid in such unit cells, by actual contact or perfect diffusion.

Thus, the first attempt at understanding the operation was the assumption (Sorel) of such an equilibrium unit or theoretical plate. A yardstick of column performance was then set up by: (1) calculating the number of theoretical plates which should be required under specified conditions, (2) experimentally determining the number of actual ones used for the same job, and (3) expressing the ratio as the percent efficiency of the particular type of plate used. This system averages the column as a whole although it is known that the contacting efficiency at different levels of the column, or at different concentrations of the liquids, varies widely. This rule-of-thumb method neglects entirely the basic mechanism of the mass transfer relations which govern the performance it tries to evaluate.

The x, y Diagram and Material Balances—The "equilibrium line" is a plot of the composition of the vapor (y) in equilibrium with the different compositions of the liquid mixtures (x) on an "x-y diagram"; the "operating line" gives the liquid compositions at the different levels under the given amount of reflux; and the distance between the two lines fixes the change in composition to be expected through use of a theoretical plate. The fraction of this distance actually traversed in the re-evaporation and re-condensation on the plate defines the plate efficiency. Thus, the efficiency (Murphree) is the ratio of actual change in composition of vapor passing through a plate to the change which would occur if there were perfect equilibrium between the liquid and the outgoing vapor.

Material balances as a tool of understanding (*simply*, "What goes in comes out") have long been used with algebraic equations set up for their representation. Assumption of equality of molar latent heats makes heat balances and material balances (in terms of moles) identical. The equilibrium line always must be experimentally determined; and McCabe and Thiele balanced the number of molecules to show that all of the liquid compositions on successive plates when plotted on an x-y diagram, fall on a straight operating line. Thus, a very simple graphical representation of material balance, although not of materials diffusing, is available. The enrichments (increase in more volatile component) caused by evaporation from the plates, are plotted as the risers and the subsequent condensations (and mixing with reflux stream) on successively higher plates are plotted as the treads of a staircase drawn between these equilibrium and operating lines. This refers to theoretical plate calculations, to which must be applied the overall efficiencies above mentioned, to refer them to actual distilling columns.

H.E.T.P.—While packed columns have little use in industrial distillation by comparison with plate columns, they are extensively used in small units for laboratory analysis, testing, small-scale manufacture, and pilot plant development. Furthermore, packed columns are more widely used for gas absorption; and similar concepts prevail with this related operation. Thus, the theoretical plate concept (Peters) was used in relation to packed columns for both distillation and absorption, by the definition of the term "H.E.T.P." (height of packing equivalent to a theoretical plate). This self-explanatory concept is useful formally for evaluating packed column performance, by material balances and theoretical plates. It assumes, however, that the changes in vapor and liquid compositions are being made in unitary steps rather than by the continuous changing which obviously prevails in the packed unit.

Diffusion Coefficients—Sherwood and Gilliland advocated that packed columns be designed and their performance evaluated by the use of coefficients of diffusion of materials through the stagnant films on the vapor and liquid sides of the interface. They showed the relation between such material transfer rates and values of H.E.T.P. The fundamental nature of the diffusion phenomenon as opposed to the empiricism of the H.E.T.P. concept is indicated by the fact that the coefficients may be expected to remain fairly constant throughout a given column (a first desideratum of any yardstick of evaluation) while the H.E.T.P.'s may vary widely.

Transfer Units—A further and very far-reaching advance, built up from the diffusional relations involved, is the expression "transfer unit," and "height of a transfer unit," (H.T.U.) developed by Chilton and Colburn. So useful is this that it has come to supersede the H.E.T.P. in packed column design and evaluation and may even replace the use of the empirical theoretical plate in plate column calculations. (It also may be used in evaluating any other counter-current diffusional operations.) It depends on the integration of the differential equation set up for the amount of materials diffused through the area of film in a differential height of the column. The number of transfer units required in a column to produce a given composition of vapors in the overhead from a bottoms having another given composition of vapors, is the integral of the reciprocal of the difference between the equilibrium and the actual vapor compositions. The H.T.U. is the total height divided by this integral value.

Because of the derivation of H.T.U. from the actual diffusional mechanism of material transfer which is taking place (rather than from the equilibrium basis used for H.E.T.P.) there is a close and calculable relation between H.T.U. and the diffusional coefficients. H.T.U. has the simple and single dimension of length as compared to the several dimensions required to define the four quantities involved in a transfer coefficient. It may be applied to diffusional processes in most types of equipment.

Evaluation of Number of Transfer

Units—There is an intriguing simplicity in the statement that the number of transfer units is the integral of the reciprocal of the difference between the equilibrium and the actual vapor compositions. The reciprocal function in relation to the resistances to diffusion suggests immediately that fundamentally the transfer unit measures conductivity. (This is discussed in more detail on a nearby page, by Scheibel.)

The simplicity of this expression fades when it is considered that the equilibrium line (and sometimes the operating line) is a curve of undefined shape, and the integral can only be evaluated algebraically if some assumptions are made. Colburn developed a method of evaluation based on the assumption of a straight line over part of the range and a curved line over another part. Other assumptions in the mathematical derivation cause the method to give such an absurdity as a negative number of transfer units under some operating conditions. Another method of evaluating the integral was therefore desired; and in *Trans.* A.I.Ch.E., (April, 1942) E. G. Scheibel and the present author develop a method of general application based on the assumption of a curved equilibrium line throughout the entire range. Simple line charts have been prepared for determining the number of transfer units from terminal values of vapor and liquid compositions in the column so that the calculation of transfer units need be no more difficult than appeared at first.

Multicomponent Systems—All of the above considerations were based on only two components in the liquid. The theory involved in the separation of three constitutents in a column is not much different; two may go to one end (top or bottom) and one to the other. Likewise, four or more components introduce complexities of degree but not of kind to the theory. Not so to the computations, however, where a solid graphical system is necessary to represent three components in three dimensions (two components are represented on a plane of two dimensions, and a single component may be expressed on a unidimensional vapor pressure line.) If the same reasoning follows, a four-dimensional system might graph as many components. A petroleum fraction having only eight components would stagger the imagination in an eight-dimensional representation. Algebraic computations on two-dimensional sheets of paper have been developed for such systems and they also are tedious in the ramifications necessary for a reasonably precise solution.

EQUIPMENT

Bubble Towers—Equilibrium in a heterogeneous system is usually obtained by subdividing the two phases and intimately mixing the subdivisions. The usual bubble-cap rectifying column accomplishes this mixing by bubbling vapors through the liquid. Mechanical power for this agitation is supplied by the expansion of the vapor from the higher pressure at the base to the lower pressure at the condenser.

One reason for the great popularity of the bubble tower as a type of contacting equipment is because the mechanical power required for agitation is so readily available, merely by increasing the pressure in the still pot. This expansion energy is always extremely small by comparison with the total heat energy required for the initial evaporation.

Many designs of bubble caps have appeared in attempts to give more and better mixing of the vapor streams issuing therefrom with the liquid on the plate. In the bubble rising on a plate, there is a diffusion of vapor from the center of the bubble to the periphery, with the molecules of the less volatile material tending to reach the periphery and being condensed at the interface. An equivalent molecular quantity of the more volatile component is then re-evaporated from the surface and diffuses toward the center of the bubble. This action evidently proceeds very rapidly; and the diameter, in any case, is small. No outstanding improvement in bubble-cap design has been announced in recent years; and a well-recognized type of high efficiency is shown in Fig. 1.

Arrangement of the caps on the plate and the addition of various baffles and gadgets for cutting down entrainment, have received some attention. More consideration has been given to the liquid removal from the plate through provision for overflow of reflux wash. The usual downcomer arrangement formerly was merely a few lengths of pipe fastened through the plate in such a way that the upper edge acted as a weir and the pipe itself acted as a conduit for the liquid to the plate beneath. As distilling columns became larger and required larger downpipes, it became desirable to separate the two functions of the downpipe—i.e., the collecting or weir action and the conducting action. Separate weirs were then introduced and the downpipes could be made smaller for a given downflow, since in the earlier types the collecting action accommodated less liquid than the conduction action. Fig. 2 shows the next step of providing a weir for collecting the overflow and then also providing a weir for distributing the overflow uniformly to the plate beneath.

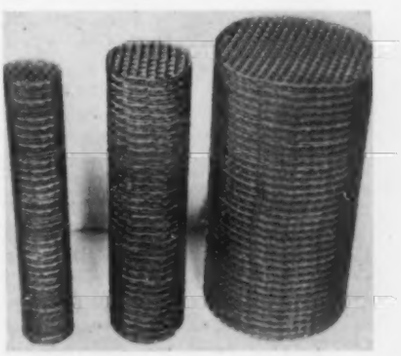
As columns became larger, disadvantages of this diametral flow across the plate appeared. An hydraulic gradient is necessary to accomplish this flow and the caps closer to the side where the flow enters the plate have a higher level of liquid (seal) than the caps on the far side, adjacent to the overflow weir. Resistance to vapor flow will be less on the one side, and more vapors will rise through the caps next to the overflow weir. Such a condition greatly decreases efficiency if the overflow is considerable. A next step, shown in Fig. 3, is a radial rather than a diametral crossing of the plate, achieved by placing one downflow on the axis and those from the next plate at points near the periphery. The liquid has only half as far to travel as in the diametral flow and the seal on caps is more uniform due to reduction of hydraulic gradient. On the adjacent plate the liquid flows from points near the periphery to the center and thus alternates center to side and side to center. It may be shown that such an action is less efficient theoretically from the standpoint of scrubbing the vapor, because the length of travel, and hence counter-current washing or contacting efficiency, is less. In a large column a few extra plates are usually installed to overcome this slightly lessened efficiency, in order to secure the advantages of the radial flow as compared to the diametral flow.

That parts of the plate will receive relatively little washing action is shown by Fig. 3. Thus, in the spaces marked *A* there will be an excellent flow of reflux wash, while in *B* smaller amounts of liquid will be flowing, and in the spaces marked *C* the vapors rise through relatively stagnant pools of liquid and have little contact with entering reflux wash.

A construction patented by the Vulcan Copper & Supply Co. for taking full advantage of the radial flow is shown in Fig. 4 wherein true radial flow is obtained because every point on the periphery of the plate is a point on the overflow weir. This construction has been found to be particularly advantageous in large columns to utilize all parts of the plate, and in smaller columns where the washed liquid is extremely large it allows a plate to handle very large amounts of downflow.

Trickling Columns—Little advance has been made in the use of packed distilling columns although there is an appreciation of the need for redistribution of the liquid wash at successive levels, due to the tendency for chan-

Tower packing of the Stedman type



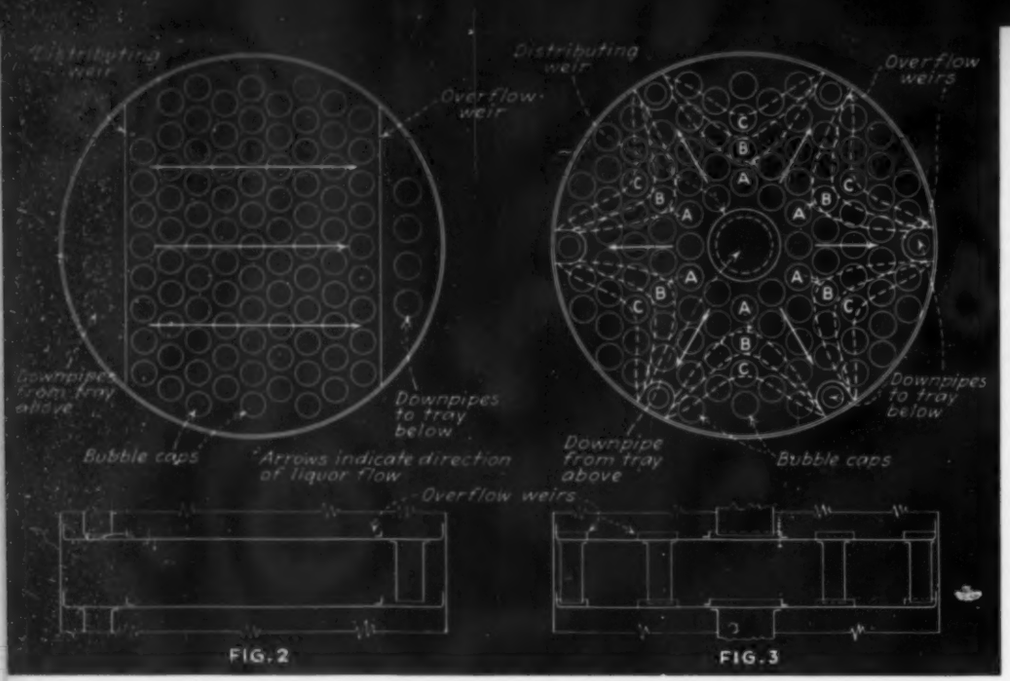


Fig. 2—Overflow weir provided for collecting downflow gives cross flow of liquid on plate. Fig. 3—Showing passage of liquid directly to side downcomers. In this arrangement more or less stagnant pools of liquid are left near the periphery

neling, particularly near the shell of the column. Internal sloping shelves, extending inwardly from the shell for 1/5 to 1/4 of the radius, throw back wash liquid running down the wall. They, of course, disrupt vapor flow and reduce the effective cross-section and hence the capacity, but they do tend to reduce the channels which either fluid may find to pass to the exclusion of the other. Most distillation engineers feel that the use of large-size packed columns is still questionable because of the difficulty of guaranteeing proper distributions of the two streams and the prevention of channeling.

Many shapes of packing have been advocated. Each is claimed to have more surface, better distribution, less hold-up, and other advantages. These packing shapes vary from the most complicated and carefully-worked-out geometric surfaces to the most haphazard shapes. One engineer, faced with the necessity of obtaining cheap packing, gave a laborer a pair of leather gloves, goggles, a railroad iron and a pile of disused bottles. The neck of each bottle was grasped, the bottle smashed, and that part of the neck remaining in the hand was tossed into the column. An efficiency comparable to commercial materials was claimed.

One reason for using a packed column is to take advantage of its relatively low pressure drop, since no static liquid head is involved as in the seals of the bubble-cap column. For high-vacuum work, where the pressure drop through the column is the limiting factor in obtaining a low boiling point at the bottom, some sort of packed column is often used.

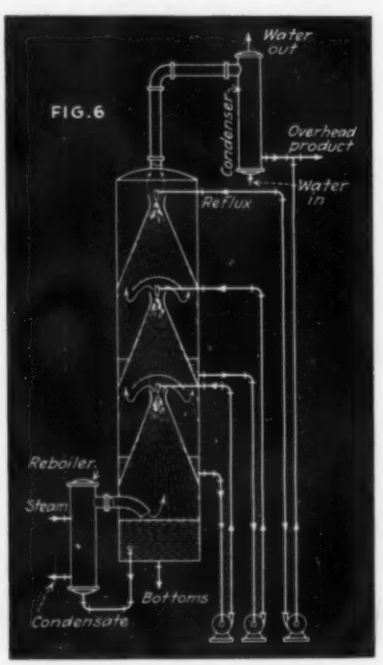
One of the large distillers of whiskey has found, for example, that the operation of the beer still at temperatures not over 90 to 100 deg. F. prevents the building up of undesirable flavors due to the breaking down at normal beer still temperatures of various protein materials in the mash. A column with very large cross-section was purchased for operation at the high vacuum required; but it was impossible with the packing used—wooden grids—to obtain sufficient rectifying efficiency in a column height of 60 ft.

The Stedman Column (Foster-Wheeler) has shown high efficiency, particularly in high-vacuum work; and while this is normally classed as a packed column, it appears to have some of the essential features of a plate-type column. It uses a screen mesh having openings small enough so that the liquid fills the openings and will travel along the mesh due to capillarity. By proper direction of the flow horizontally and vertically in between the mesh so formed and spaced, the vapors pass back and forth in contact with the upper and lower surface of adjacent closely-spaced "plates," to contact liquid films by capillarity, and to move in the direction specified by the design. A high efficiency per unit of height is thus realized, because so many "plates" are installed in a given height—about eight per inch. The individual "plate" efficiency may be rather low—averaging possibly around 5 to 8 percent, but this is compensated for by the large number so that the H.E.T.P. may be in the neighborhood of 1½ to 2 in. The pressure drop varies across this column with different liquid and vapor velocities somewhat differently than for other packing since, as the liquid down-flow increases, it reduces the available cross-sectional area for the vapor passage due to the filling of the capillary spaces and the partial bridging of the vapor passes. This is a point of theoretical as well as practical interest.

One of the oldest types of plate column is the so-called "shower" type where the liquid wash falls from plate to plate in a film or spray, through which the vapors pass. This has been revived (Lummus) with successful results in a form diagrammed in Fig. 5. In a typical tray, reflux liquid caught on a solid tray segment *A* is passed over a distributing notched weir *B* to a perforated section *C* extending across the tower width. The descending "shower" is then contacted by the ascending vapors passing at right angles through the liquid "shower" stream. Advantages claimed are high density of heat removal in those cases where it is desired to remove heat or supply additional reflux at an intermediate section, low pressure drop, and high permissable vapor velocity. Higher vapor velocities lower the efficiency, so that the number of trays is increased for large vapor loading.

Mechanical Columns—One column showing a high efficiency under extremely high vacuum operation has been the Vulcan Spray Distilling Column, Fig. 6. Vapors rise through cones at the apex of which there are spray nozzles designed to fill the cone with a spray of reflux wash. The liquid is recollected and pumped through the next lower nozzle. Each spray chamber has shown in tests to be equivalent to one to five or more transfer units. This is possible because there is a countercurrent washing action of vapor and liquid in each spray chamber rather than the *approach* to a single equilibrium condition on a bubble tray. Material transfer is between liquid droplets and the rising vapor, and in this case the liquid is the dispersed phase. The success of this column proves erroneous the long and commonly held belief among distillation engineers that diffusion to and from liquid droplets in a bulk vapor phase would be slow and

Fig. 6—Vulcan conical spray tower



ineffective by comparison with diffusion to and from vapor bubbles in a bulk liquid phase. The energy required for contacting the two phases is supplied by external mechanical power. Expansion of the vapor itself would cause an undesirable higher pressure. The power consumption for driving the pumps is, however, insignificant compared to the total energy used in distillation.

Another mechanical column depending on external energy to give the distribution of phases is the Podbielniak Centrifugal Contacter. In effect, this is a spiral of stainless steel ribbon so held between the end plates of a "spool" that the individual layers are spaced a fraction of an inch apart, to give a snail-like effect. The spiral is rotated in the winding direction and the liquid reflux which is fed into the center forms a thin film flowing outwardly on the entire outer surface of each channel because of the centrifugal action. The unit is encased in a chamber supplied with vapor from the still and the vapor flows counter-currently from the outer end toward the center where the vapor discharge pipe is located on an axis. The desired column efficiency is obtained by varying the length of the spiral and thus the length of the counter-current contact of liquid and vapor film. Here again diffusion operates differently from the usual bubble-cap column. By taking advantage of the centrifugal force to direct the liquid flow and a small pressure drop to direct the vapor travel, a very long and positive counter-current travel for the two phases may be achieved. The film interface is continuous. No data are available on the performance of this unit; but it has been stated that the volume of the unit might be only one-fifteenth as great as that required for a regular bubble cap column of equal capacity and efficiency.

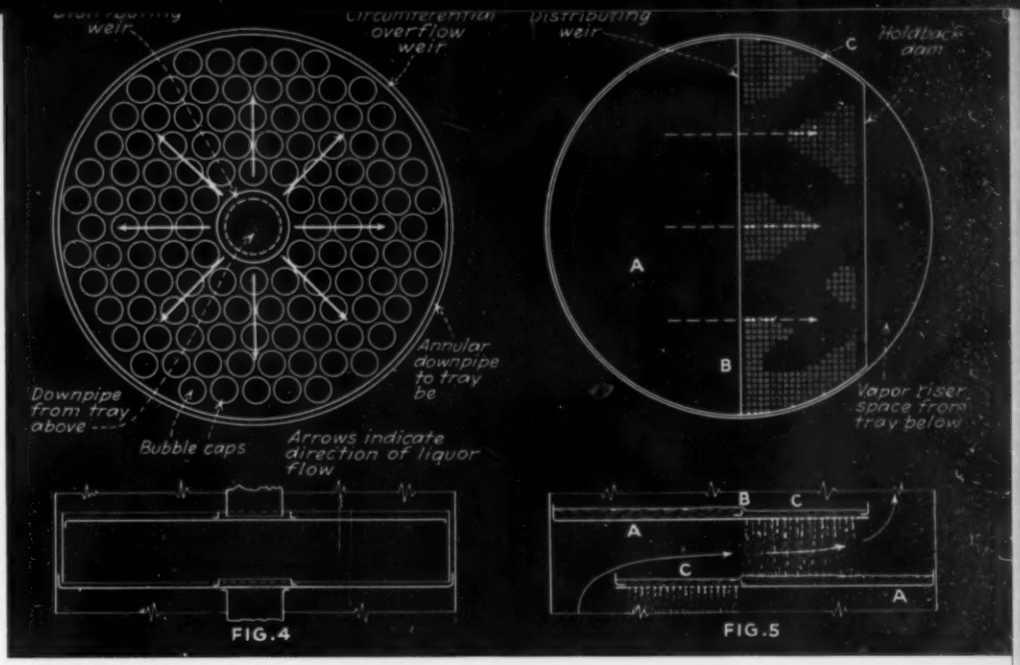
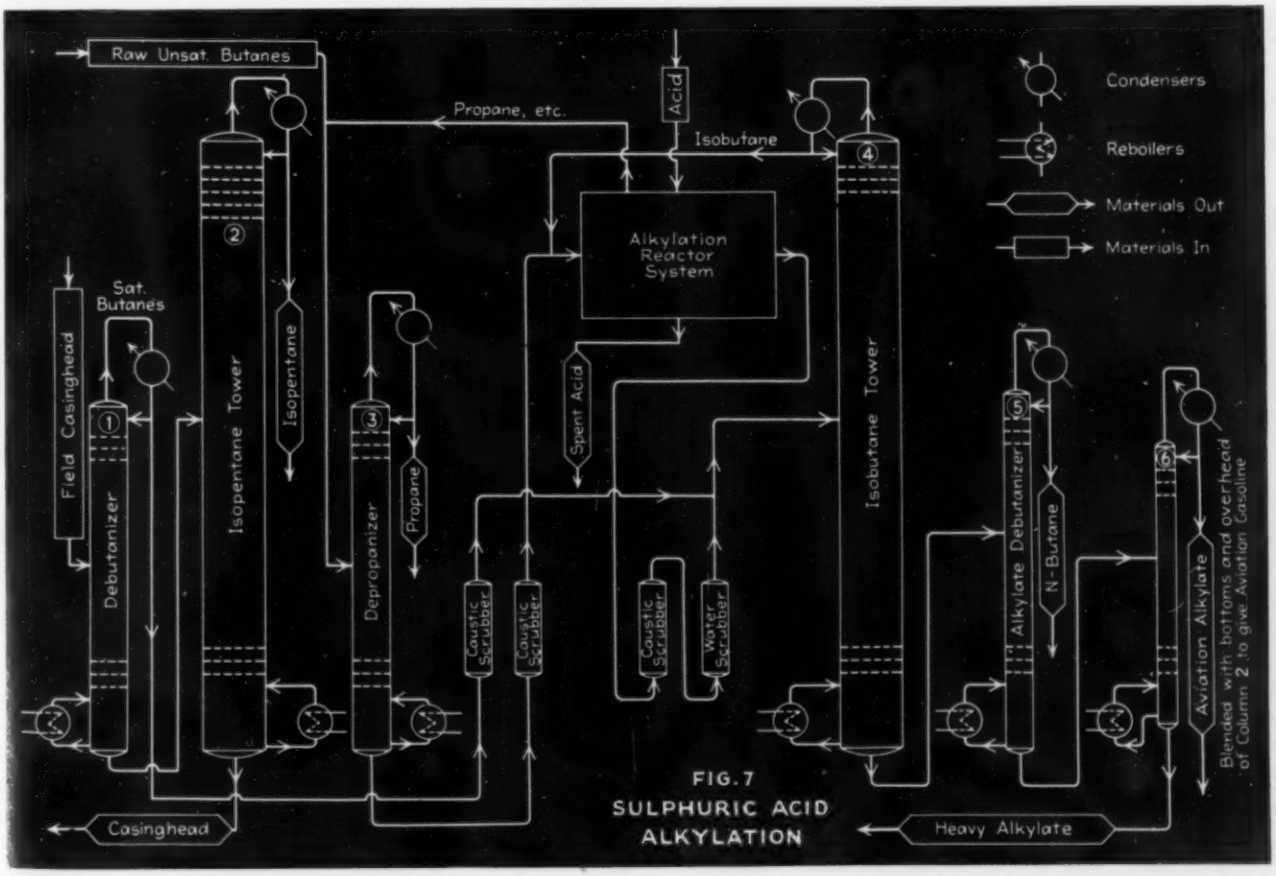


Fig. 4—Radial flow of liquid obtained by the use of a peripheral overflow weir.
Fig. 5—Shower type plate showing flow of liquid and of vapor

PROCESSES

There have been numerous advances in rectifying technique in recent years. Probably the most notable single one is the increasingly large use of continuous distilling equipment to take advantage of the many advantages resulting from continuous methods. A corrollary is the complete instrumentation

Fig. 7—Flowsheet of sulphuric-alkylation process including materials preparation on left, chemical reactors in center, and products separation on right



of modern distillation plants. Not only are all variables indicated, recorded and controlled in the automatic installations, but the most intricate devices of cams and clockwork change the pattern of operations and feeds in those sequences where molecular interactions and separations are interspersed. The distilling column itself is more and more a vessel and means of combination of materials (chemically) by the separation of reaction products (physically).

The use of the distilling column as an individual separating tool is usual in the set up of manufacturing processes, and the normal calculations for efficiency, etc., may proceed with some surety in many cases. Related uses, as a tool for specialized separating actions involving many steps or procedures more or less removed from "straight rectification," are becoming increasingly familiar. A few of these will be indicated as representative of the versatility of the tool.

Alkylation to Give Aviation Gasoline—Column after—or on—column, as tools for separating petroleum fractions, are familiar. Some of the more recent examples of multiple units are in the alkylation processes for producing aviation gasoline by synthesis of the C_8 molecules from lighter components which have little value as such—principally iso-butane and butylenes. The latter are found in gases from refinery cracking. The iso-butane is separated from field casing-head stock. A part of the residual stock is also used—together with some of the iso-pentane stripped therefrom—in blending with the synthetic alkylate to give the final aviation gasoline.

One of the processes (M. W. Kellogg Co.) is diagrammed in Fig. 7. It may be divided into three sections: *A*, feed preparation; *B*, alkylation reactor; and *C*, recovery system.

A. Field casing-head is rectified in Column 1 to separate overhead all butanes which, after caustic treatment to remove hydrogen sulphide and mercaptans, go to Column 4 of the recovery system. Bottoms from Column 1 are separated in Column 2. Iso-pentane goes overhead; de-isopentanized casing-head stock goes to bottoms; and part of each is used for subsequent blending. Cracking gases, mainly unsaturated butanes, are fed to Column 3 to be stripped of propane and lighter materials for removal from the system, and the butanes in the bottoms pass, also after caustic treatment, to the reactor system.

B. Chemical combination of iso-butane and iso-butylene occurs, favored by an excess of the former which is intimately mixed with strong sulphuric acid. A small vapor stream from the reactor goes back to Column 3 to strip any remaining propane.

C. The reaction product is decanted of sulphuric acid, washed with water and caustic, and is passed to Column 4 for stripping the excess iso-butane for return to the reactor. The bottoms from Column 4 go to Column 5, which separates the normal butane overhead. The bottoms from 5 are separated into lighter and heavier fractions; the overhead, aviation alkylate, is blended with the desired amounts of both bottoms and overhead from Column 2, to give the finished aviation gasoline.

Close Fractionation with Multiple Side-Streams—One of the oldest rules in rectification is that it takes one less continuous column than the number of substantially pure fractions which are to be made of a given liquid mixture. The Brugma Process (Foster-Wheeler Co.) appears to violate this rule in petroleum distillation where there are usually many components in each fraction. Fig. 8 diagrams a three-column set-up which is used to separate 8 fractions. In theory an additional column would separate 16 fractions, another column 32 fractions, etc. (The number of columns is the power to which 2 must be raised to give the desired number of fractions.) The stock charged to Column 1 is separated into overhead and bottoms which are then separately fed to intermediate plates of Column 2. Column 2 separates overhead and bottoms, as well as two side-streams intermediate between the two feeds. All four fractions from Column 2 are closely-cut and are fed to respective levels in Column 3, which separates closely cut overhead bottoms and two fractions between each two feed plates. Thus, a total of eight fractions is withdrawn. It is not claimed that a lessened number of total plates (total fractionating ability) is required as compared to the seven columns which would normally be used for making eight fractions. (In fact, it would appear that a larger total number of plates would be required.) It is claimed, however, that considerable heat economy results since the ultimate fractions in Column 3 are all made simultaneously by means of a single heat supply at the base. Fewer condensers and re-boilers are thus necessary. Heat supply would be that for the most difficult separation,

Fig. 8—Flowsheet of Brugma process for multiple-draw columns

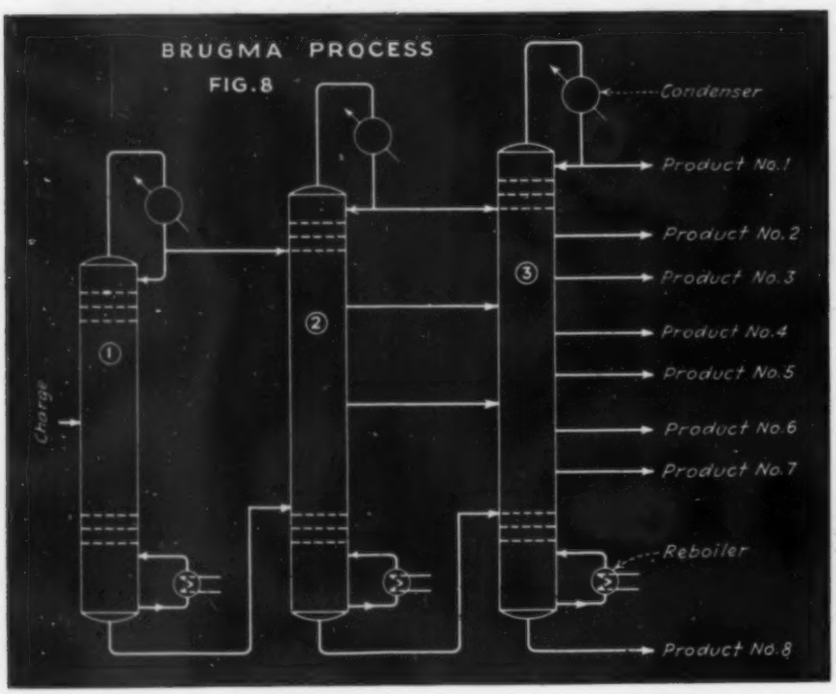
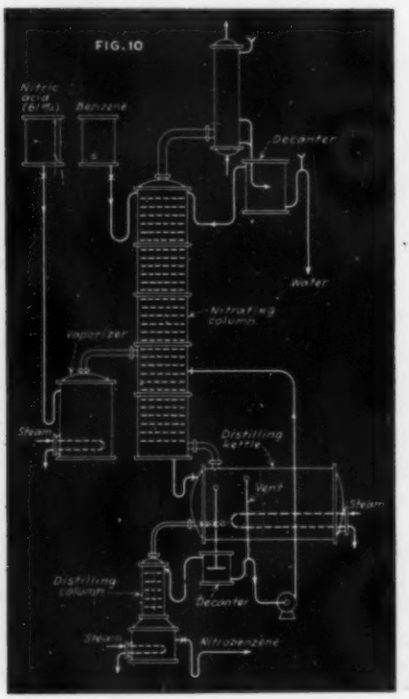


Fig. 10—Flowsheet for nitration of benzene without sulphuric acid



and the heights of the column allowed for each separation (i.e. between adjacent draw offs) would be governed by the relative column efficiencies required.

The rectification in Column 3 might be compared to the use of live steam at the base of a beer still. There the complete condensation of steam in the lowest sections of the column is necessary so that none goes overhead. In Column 3 a similar situation exists where the fractions must be kept separate through heat interchange. A few more plates than necessary in the usual separation might be required for each fraction in the final column, just as the use of open steam in the base of a beer still requires some additional rectifying efficiency. A very efficient rectifying unit would have to be used for Column 3 to keep from excessive height.

Azeotropic Distillation—A third component is often added to increase the relative volatility of one of the pair in the mixture to be separated, with respect to that of the other, and thus enhance the ease of separation. Water may thus be readily separated by adding an insoluble liquid which "steam distills" it out of a solution. This azeotropic "withdrawing agent" is charged once and for all to the distilling column and circulates from it through a condenser, decanter, etc. Such a system has been exemplified in the simplest case with regard to acetic acid, in a recent article, (*Chem & Met*, p. 91, June 1941). Its use in the more complicated field of alcohol dehydration dates from the first of the century and has produced most of the gallonage of absolute alcohol. Under pressure, ether is useful (Vulcan) because it is the only material which increases the relative volatility of water without affecting that of alcohol. (*Trans.* A.I.Ch.E., **36**, 785, 1940). Fig. 9 diagrams a process which, with the regular distilling units for spirits production, gives an added heat cost of only 1 lb. of steam per gal. of alcohol dehydrated by the use of ether under a pressure of at least 100 lb. per sq. in.

A modification of this use of an "entrainer" for carrying off water formed in a chemical reaction is used in the manufacture of esters, and has been discussed in detail by Groggins ("Unit Processes in Organic Synthesis," McGraw-Hill Book Co., 1938), and mentioned in various applications (Othmer, "Partial Pressure Processes," *Ind. & Eng. Chem.*, **33**, 1106, 1941). One of these is the nitration of a hydrocarbon such as benzene by nitric acid without sulphuric acid, and the removal of the water of reaction in a steam distillation with benzene (Fig. 10). The separating action of the distilling column plus the time of contact for the chemical reaction are factors to be considered in the design. The related nitration of toluene while in mixture with other C_7 hydrocarbons coming from reforming operations may be accomplished in the same manner to give a simultaneous reaction and separation.

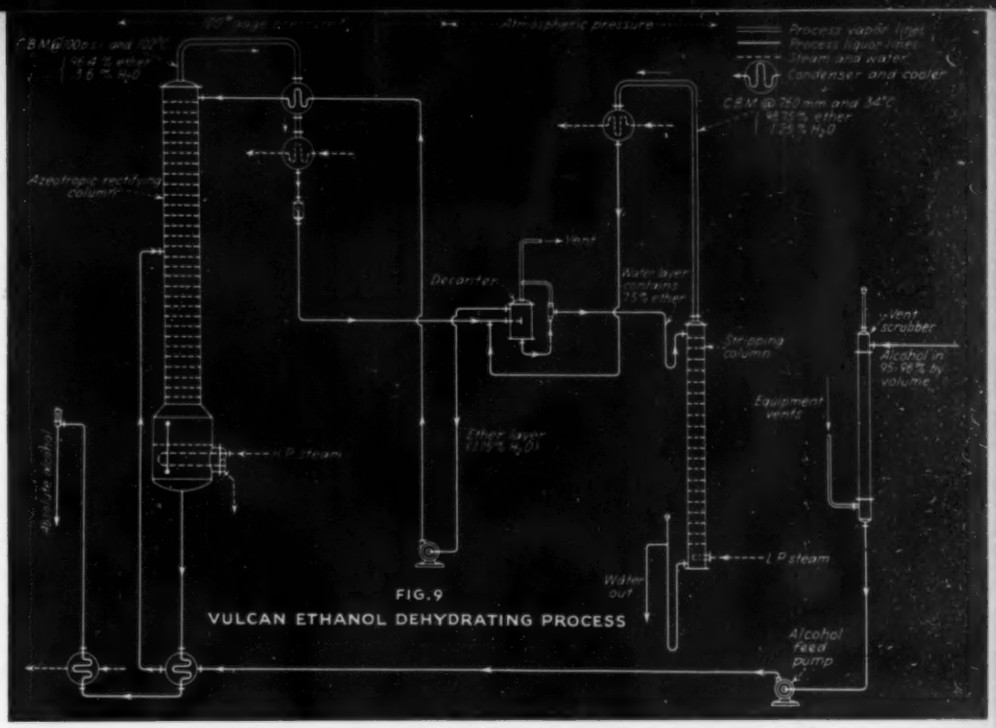


FIG. 9
VULCAN ETHANOL DEHYDRATING PROCESS

Fig. 9—Flowsheet of Vulcan dehydrating process for ethyl alcohol using ether as dehydrating agent

An operation apparently similar to azeotropic distillation, in that two liquid phases are involved, is the use of an extracting solvent for removing one of the components of a rising vapor stream. Thus, a high-boiling solvent in the Albin-Suida process (*Chem. & Met*, N. W. Krase, Nov. 1929; T. C. Albin, July 1932), is pumped as a liquid into the top of a distilling column fed with a vapor stream of acetic acid and water. A diffusional operation takes place wherein the solvent washes the solvent-soluble material, acetic acid, from the vapor stream and allows water to pass overhead. This extraction is similar to the operation taking place in an azeotropic column. Acid and solvent pass out the bottom to be separated in a subsequent column. In effect, this may be regarded as bordering on both gas absorption and extraction, to each of which it is closely related. Here again the fundamental mechanism of the diffusion operations is indicated.

Other Methods—Oils which are insoluble in water (or in general any liquid insoluble in the pure, less volatile component) appear in some distillations. In alcohol distillation, the fusel oil byproduct of the fermentation steam-distills at a temperature lower than the boiling point of water at the base and thus it can not reach the bottom. This temperature is, however, higher than allowable at the top and the fusel oil cannot go overhead. It builds "betwixt and between," in an emulsion with the aqueous phase. This is removed in a side-stream and after gravity decantation, the separated aqueous layer is returned to a lower point for exhaustion of the water, and the fusel oil is withdrawn. (The same step is used in the demethanolizing column in a wood distilling plant for withdrawing water-insoluble tar oils.)

In a process (Vulcan) based on differential solubilities in a wash liquid, fusel oil and steam of the steam distillation are allowed to pass overhead and the alcohol therein is held down, not by the ordinary reflux action of condensation, but by addition of water to the top plate. The water is heated to a temperature above that of the steam distillation so that it will not condense this vapor fraction but will wash down alcohol from the vapors. Careful control of temperature and amount of wash water allows some of the very volatile impurities (aldehydes and other heads) to pass overhead for elimination from the system.

In some solvent recovery operations, methanol and acetone in the constant boiling mixture must be separated. Calcium chloride has the same ability to reduce the vapor pressure of the lower alcohols as it has for reducing the vapor pressure of water, but it has little similar action on acetone. Thus, if a methanol-acetone vaporous mixture rises in a column against a washing action of a concentrated calcium chloride solution, the acetone passes overhead and the methanol dissolves in the calcium chloride brine and passes out at the bottom. The methanol may then be separated from the brine at a somewhat higher temperature. This process, developed by the author in 1928, has been patented (U.S. Pat. 2,179,991).

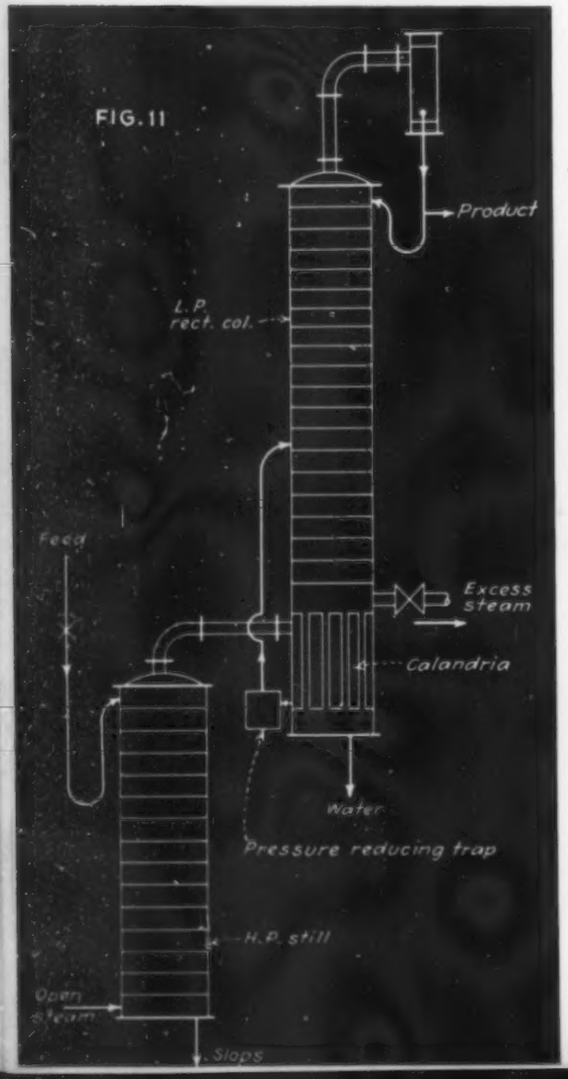
Heat Regeneration—Of the several methods used, the Vulcan vapor re-use process is probably most interesting. It is a straight-forward rectification for economical separation of low-boiling liquids from water, such as alcohol, acetone, or a combination such as that from the butanol fermentation. The application of this, diagrammed in Fig. 11, to the oldest distilling operation—the making of alcohol from fermented

mash—has shown that even in this operation advances may still be made. Steam consumption, between 16 and 18 lb. per gal. of refined spirits produced, is just half that required by ordinary distillation. This low heat cost depends on the fact that there is a considerably greater amount of latent heat in the vapors in equilibrium with the feed than will then be required to separate the alcohol from these vapors. In other words, the heat requirements for the rectifying column are so much less than the heat requirements for the beer column, that if the beer still vapors are condensed to obtain their latent heat, the condensate may be rectified to separate alcohol using less heat than the heat made available by the condensation. (It is necessary to operate the beer still under higher pressure than in the later columns, to provide temperature drop for the condensation.) The related separations in purification and dehydration may then be done concomitantly, with the excess heat available (Othmer, *Ind. & Eng. Chem.*, **28**, 1435, 1936).

Combination with Extraction—Another method, wherein the separation of these same low-boiling, water-soluble liquids may be made from aqueous solutions, using extraction, has been described (Othmer & Trueger, *Trans.* A.I.Ch.E., **37**, 597, 1941). By substituting a higher-boiling solvent for water in a solution with alcohol or acetone, for example, by means of a preliminary extraction, the heat cost and required efficiency of the necessary rectification is reduced considerably. Thus, in the recovery of the dilute alcohol formed in fermentation of sulphite liquor or from some wood hydrolysis processes, the steam cost is reduced to a small fraction of that required otherwise. Thermal data recently obtained demonstrate these savings.

Counter-current extraction has been used for at least 60 years as an adjunct to rectification for the separation of liquid mixtures where the liquids may be separated only with difficulty, or not at all, by the older processes. Extractions are preceded or followed by rectification for separation of the original liquid mix or for removing the extracting solvent from one or both liquid layers following the extraction operation.

Fig. 11—Flowsheet of vapor re-use process as applied to alcohol manufacture



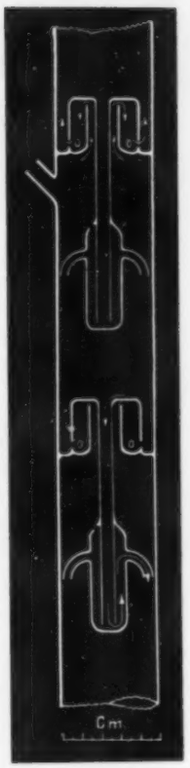
Continuous Gin Still—The manufacture of alcoholic beverages has always been an art. This is particularly true in gin manufacture. (British gin distillers moving to this country after repeal were so intent that nothing be changed from the magic of their methods that not only could none of the American improvements in distillation be incorporated—as old designs were to be followed religiously—but the copper units themselves had to be hammered out in the old way in England from copper which was refined in this country and crossed the Atlantic twice.) A continuous gin still (Vulcan) has been developed, however, which, like continuous units in general, may be operated at the optimum conditions at all times, rather than very ineffectually throughout most of the time in a batch run. This was made possible by the development of continuous feeding, extraction, distillation and discharge for the flavoring materials—solids—and by an automatic control system depending on the density of the product withdrawn. Thus, if the proof goes down during the operation, the reflux is automatically compensated to bring it back to the desired and "set" value.

The question of the time of diffusion of the essence out of the juniper berries and other extractables is one of extraction or leaching. Laboratory work on essential oils indicates, however, that steam distillation of the flavoring materials directly from the berries and other solids does proceed satisfactorily and that not much time must be given for the diffusion of the essential oils out of the berries into the spirits before volatilization.

LABORATORY EQUIPMENT AND PHYSICAL DATA

Simultaneously with the growth of plant units and processes, small-scale equipment has been developed. Now, laboratory units as efficient as those in any plant are used for testing, analysis, pilot plant development, and small-scale manufacture. A complete range of column sizes and accessories for automatic analysis, rectification of liquids and gases, in all boiling ranges, has been made available (Podbielniak). In the slightly larger sizes there are columns from one to three inches in diameter, particularly for pilot plant work. These are fabricated with from six to eight plates in a section; and as many sections may be combined as desired. They have been used between high vacuum and 60 lb. gage pressure. Fig. 12 shows one of the bubble caps of such a section, all being blown as a single piece of glass (Othmer, *Ind. & Eng. Chem.* **22**, 322, 1930). An assembly of such units and related accessories makes possible the arrangement of experimental units for distillation studies as well as for the pilot plant development of almost any distillation operation.

Fig. 12—Cross section of glass (Pyrex) distilling column for pilot use. Six to eight bubble caps and downcomers are blown integrally with shell for each section



More and better physical data continually are being made available—while the superlative degree of the adjective states the need—in vapor pressure and composition relations from the equilibrium aspect; and in performance, measurements of all kinds from the diffusional aspect. Newer methods of correlation also serve to stretch a few data over a greater range with less danger of failure or faults due to the interpolation and extrapolation.

CONCLUSION

We are able to use rectification better and more cheaply for more and more operations and in finer and more efficient equipment. Further, due to Chilton and Colburn's Transfer Unit and other methods of expression and calculation, we are better able to measure and understand, to design and predict, what can be done. And more, the art and skill and ingenuity which associates itself with practical use of any tool, shows no lack of adaptability of rectification to many services of man.

Principles and Practice In Drying of Solids

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Aimed at the drying equipment user rather than the drying engineer, the review of drying presented in the following pages attempts a comprehensive discussion not only of the underlying theory, but also of the numerous ways in which the basic principles have been applied in practice. Many equipment types are described.—*Editors.*

DRYING is one of the oldest of the unit operations of chemical engineering. Like all old arts, its latter-day development into a science has been rather slow and much of its practice is still largely empirical. Also in common with other old unit operations, drying has produced an extremely diverse body of practice, as shown by the wide range of equipment types and designs that are used. In part, of course, this comes from the diversity of materials that must be dried.

VAPORIZATION

Every liquid and solid has a characteristic vapor pressure which depends only on the material and its temperature. The vapor pressures of solids are usually small and of little, if any, interest in drying. That of a liquid is generally high and offers a means of separating the liquid from any solids with which it may be in contact. A liquid will vaporize into adjacent space until the pressure of its vapor reaches a definite equilibrium value, dependent only on the vaporizing material and its temperature.

This vaporization may take place into an inert gas without change in the magnitude of the vapor pressure equilibrium attained, provided only that the pressure of the gas is not much above atmospheric. When such a mixture of gas and vapor exists, the pressures of each are referred to as partial pressures and the sum of the partial pressures is the total pressure of the system.

Continuous vaporization of a liquid can be maintained, provided that some means is used to remove the vapor as rapidly as it forms, thus preventing the establishment of an equilibrium between liquid and vapor, and provided that the energy requirements of the vaporization are supplied. Three means are available for the removing of the vapor: (1) If the vapor pressure is raised by heating until it equals the pressure of the surrounding atmosphere, the liquid is said to boil and the vaporizing molecules are able to push back the atmosphere and diffuse into space. (2) If the vapor pressure is less than that of the atmosphere, the vapor molecules can be swept away mechanically from the liquid by an inert gas such as air, provided that the partial pressure of the vapor of the liquid in the inert gas, as it reaches the liquid surface, is less than the vapor pressure of the liquid. (3) If vaporization is taking place in a closed container, out of contact with the atmosphere, the vapor molecules can be trapped mechanically and removed from the container by a vacuum pump. Or a condenser which will decrease the energy content of the vapor and condense it out of contact with the original vaporizing liquid, can be used as an adjunct to the vacuum pump, to decrease the load carried by the pump.

These three methods of removing vapor continuously from the environs of a vaporizing liquid represent the three fundamental methods of drying. Some high temperature dryers combine the first two methods. The majority of lower temperature dryers use the second method, which is termed air drying, whether air or some other inert gas is used as the sweeping medium. Finally, the third method, vacuum drying, is available for delicate products which can be dried only at extremely low temperatures.

It should be pointed out, however, that there is fundamentally little difference between vacuum and air drying, except for the means of supplying the heat. At pressures not much above atmospheric, the voids between the molecules of a dry inert gas are so large, relatively, that the gas has no more effect on the final vapor-liquid equilibrium than if it were absent. The only effect of the air is a mechanical one, that of getting in the way of vapor molecules as they issue from the liquid and thus slowing down the vaporization.

Comparing air drying with vacuum drying: whereas a vacuum pump traps the vapor molecules and forces them from the system, the sweep of dry air literally pushes the vapor molecules from the vicinity of the liquid. Hence the two methods are equivalent except for the inhibiting effect of the air molecules and the choice between them will depend on convenience, equipment or operating costs, or the characteristics of the material to be dried.

It must be understood, however, that only a substantially dry sweeping gas is equivalent to the vacuum method, since the partial pressure of moisture in atmospheric air is often too great to permit its use in low temperature drying. Pre-dried air is actually being used in a number of low temperature drying operations which would otherwise have to be carried out under vacuum to secure equivalent results. For example, a considerable tonnage of dried salt fish is being produced through the use of air at a dry-bulb temperature of only 72 deg. F., the air being dried to a dewpoint of 36 deg. by means of lithium chloride solution.

HEAT SUPPLY

All drying operations require the supplying of heat to the vaporizing liquid, since vapor can be released from the liquid only when the heat energy of vaporization is provided. This heat can be supplied in a number of ways including conduction from heated surfaces, convection from the heated drying air, or radiation from surfaces which are at a higher temperature than the liquid. Still one other method is possible, namely, to provide the latent heat of evaporation from the sensible heat of the liquid, thus causing the temperature of the liquid to fall as in evaporative and vacuum cooling. In drying this method cannot be the primary one used, since the falling temperature of the liquid reduces its vapor pressure and thus reduces the vaporizing tendency. However, the effect is often incidental to the supplying of heat from the drying air, particularly in handling delicate products which must not be allowed to rise materially in temperature during the drying operation.

DRYING POTENTIAL

Where a liquid is vaporizing into an evacuated inclosure, or one containing a moderate pressure of inert gas, the vaporizing tendency at any time before equilibrium is reached depends on the difference between the vapor pressure of the liquid at the existing temperature, and the pressure of the vapor already in the vapor space. Thus, at the start of vaporization, the potential equals the vapor pressure. At some intermediate time, it equals the difference between the vapor pressure and the partial pressure; and at equilibrium, it is zero. Under actual drying

conditions, which are dynamic rather than static, the same situation holds. When air is sweeping the molecules of evaporating water away from the liquid surface, the drying potential is the difference between the vapor pressure of the water and the partial pressure of water in the air. In vacuum drying, the potential is the difference between the vapor pressure of the evaporating water, and the lower vapor pressure corresponding to the condenser temperature. This last statement neglects the frictional drop in pressure from the evaporator to the condenser, but the effect can be disregarded for purposes of definition.

EQUILIBRIUM MOISTURE

Previously in this discussion, no consideration has been given to effects which solids may have on the vaporizing liquid. As a matter of fact, the presence of solid materials may affect the vaporization profoundly, not only altering the *rate* at which vapor is liberated, but also changing the *extent* to which it can be released. The effect on rate will be considered later, but that on equilibrium must be discussed at this point.

There are apparently two ways in which solids can alter the vapor pressure of a liquid, and these may occur simultaneously. If a solid is soluble in the liquid, its effect is to lower the vapor pressure to a greater or lesser extent for a given temperature, and thus to decrease the available drying potential. Similarly, solids which will adsorb the liquid will also lower the vapor pressure and hence the drying potential. A corollary of this vapor pressure lowering is that materials which either adsorb or dissolve in the liquid cannot be completely dried by air which contains any of the vapor of the liquid. The reason is as follows: As such a material is dried, the vapor pressure of the remaining liquid will continue to decrease, eventually reaching a point where it will equal the partial pressure of the air. When this occurs, equilibrium will be reached and further transfer of vapor cannot take place. (Actually, of course, the equilibrium cannot be reached except in infinite time, so that the moisture content referred to is a *practical* equilibrium of approximate character.)

Many organic materials, for example, paper, textiles, leather and hair, exhibit an equilibrium moisture content. If brought in contact with air having a higher partial pressure of water than the vapor pressure of water in the material at that temperature, they will pick up moisture from the air. Conversely, they will lose moisture to air which has a lower partial pressure. Thus, hygroscopic materials exhibit an equilibrium moisture percentage which varies with the relative humidity (and to some extent also with the temperature) of the air and they can be dried completely only with air of zero moisture content. Ordinarily, if the dried material is to be stored in contact with air, there is no advantage in attempting to dry it below its equilibrium moisture content for the conditions of the storage air, since it will regain moisture up to the equilibrium point in storage. Equilibrium moisture curves for several materials appear in Fig. 1.

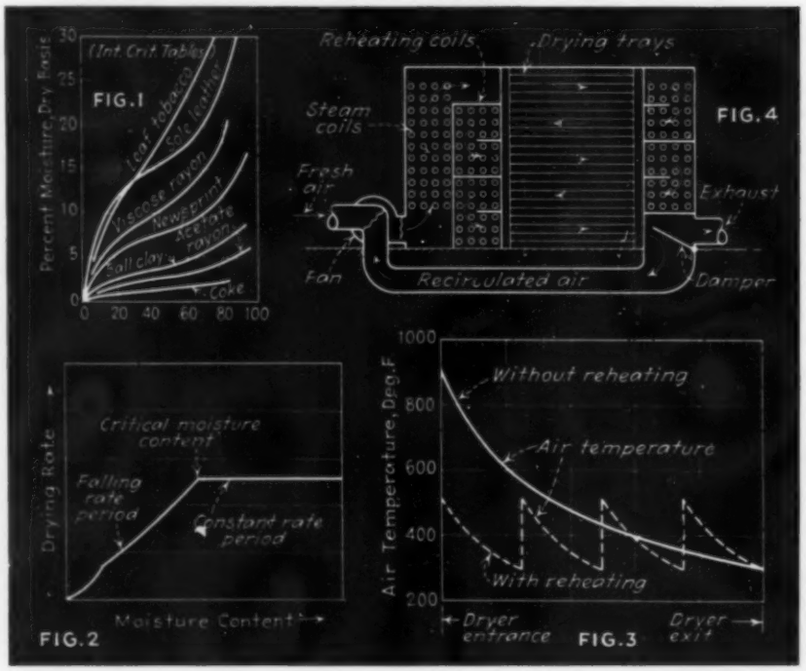
DRYING RATE

When a wet material is dried under constant drying conditions there are usually two stages in the drying when the vaporization proceeds in quite different ways, as indicated in the typical drying rate curve of Fig. 2. Ordinarily, the initial moisture content is high enough so that evaporation takes place as if from a free liquid surface, and in this case the vapor pressure will be that of the pure liquid, unless the liquid contains some of the solid or some impurity in solution. Then, as drying proceeds and the moisture content of the solid decreases, a point will usually be reached when the drying rate will begin to fall, becoming progressively less as the moisture content continues to decrease. In the initial stage, known as the constant rate period, the presence of the solid has no effect on the drying rate except insofar as it may lower the vapor pressure by solution. In the second stage, or falling rate period, the solid may not only reduce the vapor pressure by solution or adsorption, or both, but it may also inhibit the passage of liquid to the plane of evaporation or mechanically inhibit vapor escape.

The mechanism of moisture evaporation into the air stream during the constant rate period is substantially the same as that of vaporization from a free liquid surface. At the surface of a vaporizing liquid it is considered that a stagnant film of air and vapor exists and that this film is substantially saturated with respect to the vapor. Molecules of vapor diffuse through this film and into the air stream, under a driving force equal to the difference between the saturation vapor pressure of the liquid at the interface between liquid and film, and the partial pressure of the vapor in the air. The rate of flow is directly proportional to the vapor pressure, the area of the surface from which vaporization is taking place, and a coefficient of vapor weight transmission per unit pressure gradient, which is sometimes termed a diffusion coefficient. This coefficient depends on the temperature and also on the concentration of inert gas molecules in the film.

Since it is difficult to measure the film thickness, the expression for diffusion rate as actually set up employs an overall film coefficient exactly as used in heat transfer. In the latter case, the heat transfer coefficient has the form of: heat units (B.t.u.) per hour, square foot of path cross section, and unit of driving force (deg. F.). In the overall vapor transmission coefficient the form is: quantity diffused (pounds) per hour, square foot of path cross section, and unit of driving force (vapor pressure difference). The diffusion equation therefore has the form:

(1) Equilibrium moisture contents for several typical materials; (2) Drying rate curve of type characteristic of a porous granular solid; (3) Comparison of dryer air temperatures, with and without reheating; (4) Simplified diagram of reheating type cabinet dryer, equipped for recirculation of drying air



$$W = KA\ (p_i - p_g)$$

where W is the weight in pounds diffused per hour; K is the overall vapor weight transmission coefficient in pounds per hour, square foot and mm. Hg of vapor pressure difference; A is the cross sectional area of the path in square feet; p_i is the vapor pressure of water at the interface in mm. Hg; and p_g is the partial pressure of water in the air, also in mm. Hg.

It is also possible to set up the equation on two other bases, using different driving potentials. Instead of the difference between vapor pressure and partial pressure, the potential may be in terms of humidity, in which case the driving force is the difference between the weight of moisture per pound of dry air at saturation, and that in the actual drying air. Or the potential may be in terms of moisture concentration, in which case the driving force is the difference between the weight of moisture per cubic foot of air at saturation, and that per cubic foot of actual drying air. If either of these bases is employed, however, the vapor transmission coefficient must be consistent with the basis chosen, and care must be taken in employing a coefficient taken from the literature that one of the proper form is selected.

During the constant rate period when the vapor flow equation holds, the drying rate is determined by the factors of liquid temperature and vapor pressure, liquid surface, film coefficient, and air temperature, velocity and humidity. Some of these factors can be varied so as to increase the drying rate. Higher air velocity, for example, will decrease the film thickness and thus increase the film coefficient approximately as the 0.8 power of the air velocity. Altering the air flow over the film from a direction more nearly parallel, to a direction more nearly vertical, to the film will also decrease the film thickness. Or the driving force may be increased by raising the drying temperature or lowering the air humidity. Finally, a smaller state of subdivision of the material being dried will increase the surface available for evaporation and thus again increase the drying rate.

FALLING RATE PERIOD

A much more complex situation is met in the falling rate period. The point at which this period commences, as shown in Fig. 2, is known as the critical moisture content, a characteristic which varies considerably from material to material and also with the air conditions and velocity. It is high for hygroscopic materials, and low for porous or granular materials. Sherwood (Perry's Handbook, 2d Ed., p. 1520) lists critical moisture contents for a considerable variety of materials, showing that this factor ranges from as much as 300 percent moisture on the dry basis for gelatine, to as little as 3 percent for a thin layer of sea sand. It is in the range from 33 to 70 percent for various kinds of paper, in the range from 120 to 160 percent for various building boards, but in the neighborhood of 8 to 20 percent for clays and similar or even lower for certain inorganic chemicals.

With some materials it may be possible for the entire drying operation to be carried out in the constant rate period. With others, the initial moisture content may be less than the critical, in which case the entire operation is in the falling rate period.

Several different explanations are given for the falling rate period, each of which is probably correct for certain materials, or at certain times in the drying of a single material. Consider first the implications of constant rate drying. When a free or substantially free liquid surface is available to the drying air, the rate of evaporation is affected only by the factors noted in the preceding section, and not at all by the solid material (except in the case of solution). When a free moisture surface ceases to exist, several possible conditions can arise: (1) The liquid continues to move to the surface at the same rate as the evaporation from the surface, but since the free moisture has been removed, the evaporation rate decreases for one of two reasons: (*a*) The surface has become partially dry, so that the area from which evaporation takes place is reduced; (*b*) the vapor pressure of the surface moisture has been reduced owing to an adsorption effect. (2) The rate of moisture diffusion to the surface becomes less than the rate of evaporation from the surface, with the result that: (*a*) The evaporation may continue at a slower rate in a plane within the solid which recedes continually from the surface (in case the material is porous); or (*b*) evaporation may practically cease (in case the material case-hardens to the extent that vapor cannot diffuse through the hardened surface). The mechanism in the last case is particularly interesting. Once evaporation has ceased, moisture immediately begins to diffuse to the surface, thus re-wetting it. At this time, evaporation re-commences and the cycle of case-hardening, evaporation stoppage and re-wetting continues. This action may occur with such rapidity that it cannot be observed, giving rise to the belief that evaporation is continuous.

When the evaporation is inhibited by the types of action described in case (2) above, the rate of moisture movement out of the solid becomes the controlling factor, rather than the quantity of wetted surface, and the drying rate shows still a different slope or progression of slopes.

Whatever the mechanism of the falling rate period, it should be noted that during the latter part of the period, air velocity ceases to be a controlling factor and increasing the air flow can no longer improve the drying rate.

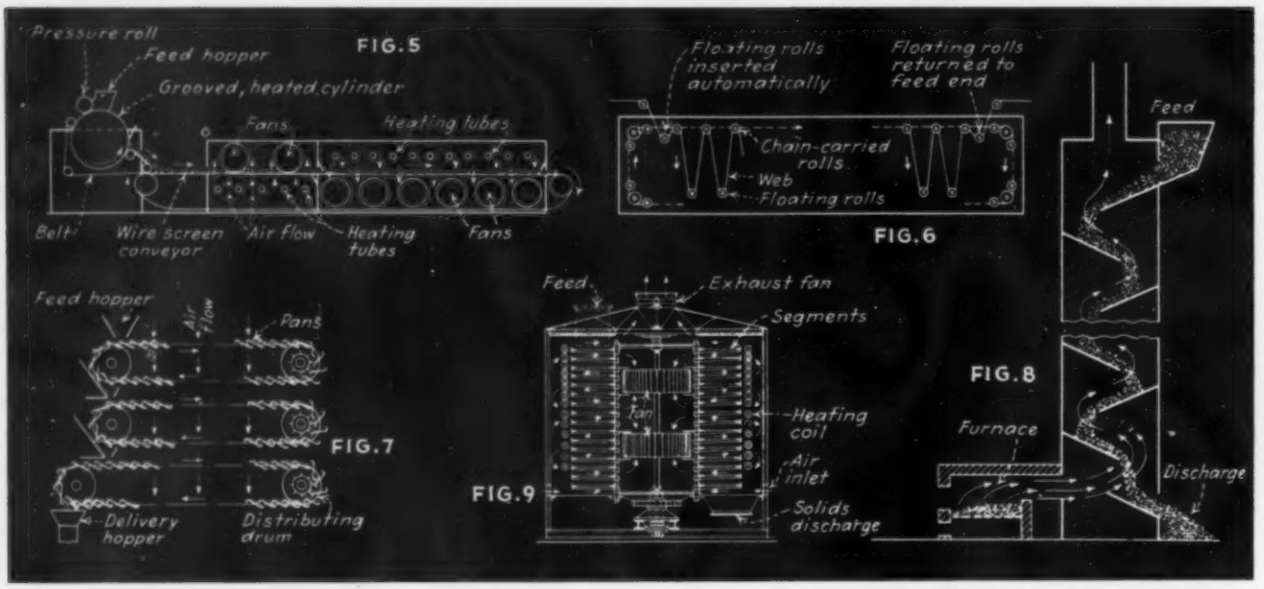
Although the conception of the falling rate period is a convenient one for study, it should be mentioned here that it is somewhat academic from the standpoint of actual dryer design. Drying rate curves of the type discussed are determined under constant drying conditions, whereas in practice conditions are usually not held constant. By varying the drying conditions a drying rate curve can be produced in which there is no constant rate period. Conversely, it is sometimes possible, even with the same material dried under a different succession of drying conditions, to produce a curve giving the appearance of a constant rate period which continues almost to the end of the drying operation.

Any attempt to reduce the characteristics of the falling rate period to mathematical expressions necessarily demands knowledge of the mechanism of passage of the water from within the material to the plane of evaporation. Unfortunately, this is the weakest spot in the entire development of the theory of drying. It can be assumed, for example, that liquid passes to the surface by diffusion, in which case the rate of diffusion of the liquid will follow a law similar to that for the diffusion of heat. It is possible to solve the integral of the equation so obtained for certain conditions, but it is an unfortunate fact that only a few actual drying problems seem to follow such a law. Or it can be assumed that the passage of moisture to the drying plane is by diffusion, affected by capillarity, gravity flow or other factors such as change in the diffusion constant (which in the calculation referred to was assumed to remain constant). Considerable experimental evidence has been adduced to show that such modes of passage as these actually are met in such materials as clay, soap, paper and sand, as shown by the tests of Hougen, McCauley and Marshall (*Trans. Am. Inst. Chem. Eng.*, Vol. 36, 1940, p. 183ff).

In the present stage of drying theory development, therefore, practical drying design appears to be limited largely to empirical laboratory methods, so far as the falling rate period is concerned. Sherwood (*loc. cit.*) has developed an empirical equation for experimental determination of drying time in the falling rate period. Taking the equilibrium moisture content as the end point of drying, the equation assumes that at any time during the falling rate period, the drying rate is proportional to the percentage of moisture still to be removed, that is, to the "free" moisture above the equilibrium moisture content. In the expression

$$\log\ (T_c - T_e)/(T - T_e) = k\,\theta$$

T_c is the critical moisture content or the initial moisture content, whichever is lower; T_e is the equilibrium moisture content; T is the actual moisture content after θ hours of drying



(5) Diagrammatic illustration of Proctor Aeroform dryer for materials requiring preforming; grooved drum is used for both predrying and preforming; (6) Simplified diagram of festoon dryer, with turning rolls to prevent stick marks; (7) Illustrating principle of Proctor reversing-pan dryer for granular solids; (8) Old type baffled tower dryer, still sometimes used for granular materials; (9) Vertical rotary shelf Turbo dryer for drying pasty and granular materials, with reheating

under constant temperature, humidity and airflow conditions; k is a constant; and θ is the time that the drying has been carried on during the falling rate period in achieving the moisture content T. The equation can be solved for k, by using the experimental time and moisture content, then solved for the time required for the desired moisture content, using the k value so obtained.

One problem in attempting to predetermine drying time on the basis of small scale experiments arises from the fact that actual drying, as already noted, is rarely carried out under the constant conditions postulated by laboratory tests. It is for this reason that most experimental work by drying machinery manufacturers is done in scale model pilot dryers, where the conditions can closely simulate those of full-scale work. An exception to this statement occurs, however, in the case of those types of dryers in which conditions are constantly averaged. With such types, results can be duplicated on a laboratory scale.

DRYER TYPES

Various writers have attempted to draw up classifications of dryer types, but in view of the great variety of designs actually used, and the overlapping characteristics, no such classification appears to be of much utility. Before discussing the dryers themselves, it may be well to consider a number of factors which are common to a number of dryer designs, including air reheating and pre-drying, and forced diffusion.

Reheating—The thermal efficiency of a dryer depends on the amount of air required to remove a pound of water, and on the temperature at which the air leaves the dryer. The greater the quantity of air needed, obviously, the more waste heat will be carried out in the exit air. In dryers in which the air makes but a single pass without reheating, high efficiency can be attained only if the initial temperature of the air is high. But such high temperatures usually cannot be obtained if the air is heated with steam. Furthermore, they are limited to materials which are initially very wet and are moving in parallel flow with respect to the air. There is also the danger of damage to the material from overheating, or even burning, if the feed should be interrupted, or the particle size is not uniform.

One method frequently used to obviate these difficulties is to reheat the air repeatedly after it has passed over part of the material. The effect of this reheating is obvious from the chart of Fig. 3. In each cycle of contacting and reheating the temperature of the air is raised only a little but the heat supplied in several reheatings is equal to that with air at an initially high temperature.

Pre-Dried Air—The use of pre-dried air for low temperature drying has been employed to some extent, although fairly infrequently, owing to the cost of the dehumidifying equipment involved. For this purpose, air can be dried by refrigeration, adsorption or absorption.

Several installations using refrigeration are in operation on glue and gelatine. Refrigeration is not the preferred method, since the air must be reheated from the low temperature used to effect condensation of its moisture. However, its use appears to have been dictated at times by the availability of the necessary refrigerating equipment. Adsorption drying of air with silica gel and activated alumina has been employed to a considerable extent in cable drying installations, and at least one commercial installation for the drying of salt fish, which has already been mentioned, employs absorption drying with lithium chloride solution.

Forced Diffusion—During the falling rate period, the factor controlling the drying rate in most cases is the rate of passage of moisture from within the material to the surface. If a means were available for applying heat directly to the moisture within the material, drying could be considerably accelerated. As a matter of fact, such a method exists in the process of "forced diffusion" originally suggested by Professor E. Schmidt, of Berlin, in 1924. The same effect as heating the moisture inside the material can be had if the temperature of the surrounding air is lowered to be less than that of the material. When the liquid temperature is higher than that of the air, the temperature gradient increases the rate of moisture passage according to the law of liquid flow through capillaries. This lowering of air temperature with respect to the material can be accomplished by proper design and control of a reheating type of counterflow dryer so that in several cycles of reheating in the part of the dryer where moisture diffusion is controlling, the material passes through a number of zones where the temperature is alternately higher and lower than that of the material. The same effect can be obtained in batch dryers by alternately raising and lowering the temperature.

BATCH DRYERS

Batch dryers are used to a considerable extent where the amount of material to be dried is relatively small or where the product drys very slowly. Batch dryers suffer from high investment cost in comparison with continuous equipment when the capacity is large. Conversely, for small capacity, the cost of batch equipment is generally less than for continuous dryers. Another disadvantage of batch dryers is the difficulty of fitting the dryer into an otherwise continuous flowsheet. Furthermore, the space and labor requirements of batch equipment will generally be greater.

One of the simplest and at the same time oldest and crudest methods of drying is the so-called loft dryer which consists of a room or compartment containing steam coils or some other method of supplying heat, without any particular provision for air circulation and the attainment of uniform drying conditions throughout the room. At one time, leather, textiles and paper were largely dried in such equipment. Fortunately, the disadvantages of the loft dryer from the standpoint of low capacity and poor control are now understood quite generally.

Certain materials which were formerly dried in loft dryers are still handled most conveniently in apparatus of somewhat similar characteristics, but with means provided for accurate control of temperature, humidity and circulation of the air. Dryers of this new type fall into the classifications of cabinet or compartment dryers which are found in a large number of variations, depending on the type of material to be dried. Included in this group are the shelf dryers which are used to a considerable extent for the drying of relatively small quantities of fairly valuable materials, such as pharmaceuticals and dyes.

In general, a cabinet dryer consists of an inclosure containing racks for trays, or space into which trucks carrying trays can be pushed by hand. In the atmospheric type, the better designs provide for careful control of air circulation and recirculation, as well as for reheating. In a typical design (Fig. 4), the outside air is brought in and forced by fan pressure through heating coils and over a group of trays, parallel to the surface of the material. The air is then reheated and passed over another group of trays. After several reheatings, part of the air discharges while the remainder recirculates to the suction of the fan for mixing with the fresh air and passage again over the material being dried. With such a dryer, an extremely accurate drying schedule can be maintained. For example, at the start of the operation, when the material contains much moisture, 100 percent outside air can be passed over the material and exhausted without recirculation. As drying continues, either in order to avoid case hardening, or excessive temperature rise in the material as it becomes more nearly dried, part of the air can be recirculated for control of air moisture content while the dryer temperature can be lowered simultaneously, if desired. Dryers of this type lend themselves readily to automatic cycle control of temperature and air humidity.

Where low drying temperatures must be used, a modification of this type of dryer is readily operated under vacuum. In this case, the shell is generally of cast iron and the shelves on which the trays are placed are cored to permit the entrance of heating steam. A manifold giving access to the spaces above the several shelves is connected to a condenser and vacuum pump or jet exhauster.

Agitated Dryers—Another type of batch dryer which is used for comparatively small quantities of material is the agitated type which is built in several variations. Agitated dryers lend themselves particularly well to the drying of heavy suspensions, pasty materials, and pulverized solids which flow readily. In general, there are two types, the pan or hot-plate type, and the rotary type, both of which are suited to either atmospheric or vacuum operation. The pan type is a vertical cylindrical vessel with flat bottom, generally inclosed and made either of cast iron or welded sheet metal. The lower part of the vessel is jacketed for steam or other heating medium, while a scraper type agitator is provided, driven from a central shaft. This type of dryer is used for such materials as wood flour and for the crystallization, graining and drying of ammonium nitrate. It is readily operated under vacuum if constructed to withstand the necessary external pressure.

The rotary agitated type is a steam jacketed cylinder or sometimes a trough, containing a centrally located horizontal shaft carrying either a spiral ribbon agitator or pug-mill type blades. Sometimes the atmospheric type has a continuous screw conveyor flight for simultaneous drying and conveying.

CONTINUOUS DRYERS

Continuous dryers offer, among other advantages, the greatest possible drying capacity in a given amount of space. Although not all continuous dryer types afford as close control of drying conditions as may be necessary for some materials, it may be stated that the majority of all drying problems can be solved successfully on a continuous basis.

Continuous dryers have a number of characteristics not available in batch dryers. For example, the designer can usually choose the best direction of air flow relative to the material. And in some types he can zone the temperatures and humidities.

Air Flow Direction—In most types of continuous air dryer it is possible to choose whether the direction of air flow is to be parallel to or counter to the flow of the material. Counterflow, it is clear, will permit higher heat transfer and a lower final moisture content of the material, because it gives a higher drying potential as drying approaches completion, but many drying problems require parallel flow for a variety of reasons. For example, counterflow results in heating the material to the highest temperature of the drying air, at the discharge end, which results in a waste unless it is necessary in obtaining the desired final moisture content in the material. Another factor, sometimes more serious, is the tendency for certain materials to form a hard surface or to check or crack on the surface during the latter stages of drying, unless the drying rate is decreased toward the end of the operation through the use of lower temperature air of higher humidity. Clay products, for example, tend to dry on the surface at the beginning of the falling rate period when internal diffusion becomes controlling. If the attempt is made to maintain the same high drying rate as in the constant rate period, surface cracking, checking and warping are likely. The same situation is encountered in the drying of lumber and the cure in both cases is to complete the drying at a humidity and temperature which will reduce the rate of surface evaporation to that of moisture diffusion from the interior.

TUNNEL DRYERS

Although the number of fundamentally different principles employed in continuous dryers is not large, variations in mechanical design are legion. One of the largest classes in point of design variations is the group known collectively as tunnel and conveyor dryers.

Fundamentally, a tunnel dryer consists simply of an elongated chamber through which the material to be dried passes, with provision for bringing the material into contact with a suitable sweeping gas and with means for supplying the latent heat of evaporation. Numerous variations are encountered in methods for conveying material through the dryer, in means of supplying heat, in air flow, and in control to assure the desired drying schedule.

Tunnel and conveyor dryers are adapted to the handling of many types of material. For example, they are used for moist filter cakes, for pulverized and granular materials, for continuous sheets and webs such as paper and textiles, and for heavy units such as lumber and clay products. Trucks and cars may be used for carrying the material, as well as almost any type of conveyor. When trucks and cars are used, generally some pushing or

conveying mechanism is employed to move the string of trucks along when a new truck is entered into the dryer and the one which has completed the cycle is removed.

Both conveyor and truck dryers may readily be zoned for the maintenance of suitable drying conditions within each zone. They may also employ recirculation of the air, either through the dryer as a whole, or through individual zones where the air is reheated.

Although there are variations in each class, the types of conveyors employed in tunnel dryers can be listed roughly as belts and bands, festoons, pans and vibrators. Belt type dryers employ both solid, imperforate belts and, somewhat more commonly, mesh or perforated belts to permit drying from both sides, or to allow through circulation of the drying air. Mesh belts are preferable where they can be used without loss of material through the mesh. Through circulation permits contact of the air with all sides of the particles, thus reducing the distance through which the water must travel to reach the plane of evaporation. This method is suitable for granular materials, provided they are free of fines, and for fibrous materials.

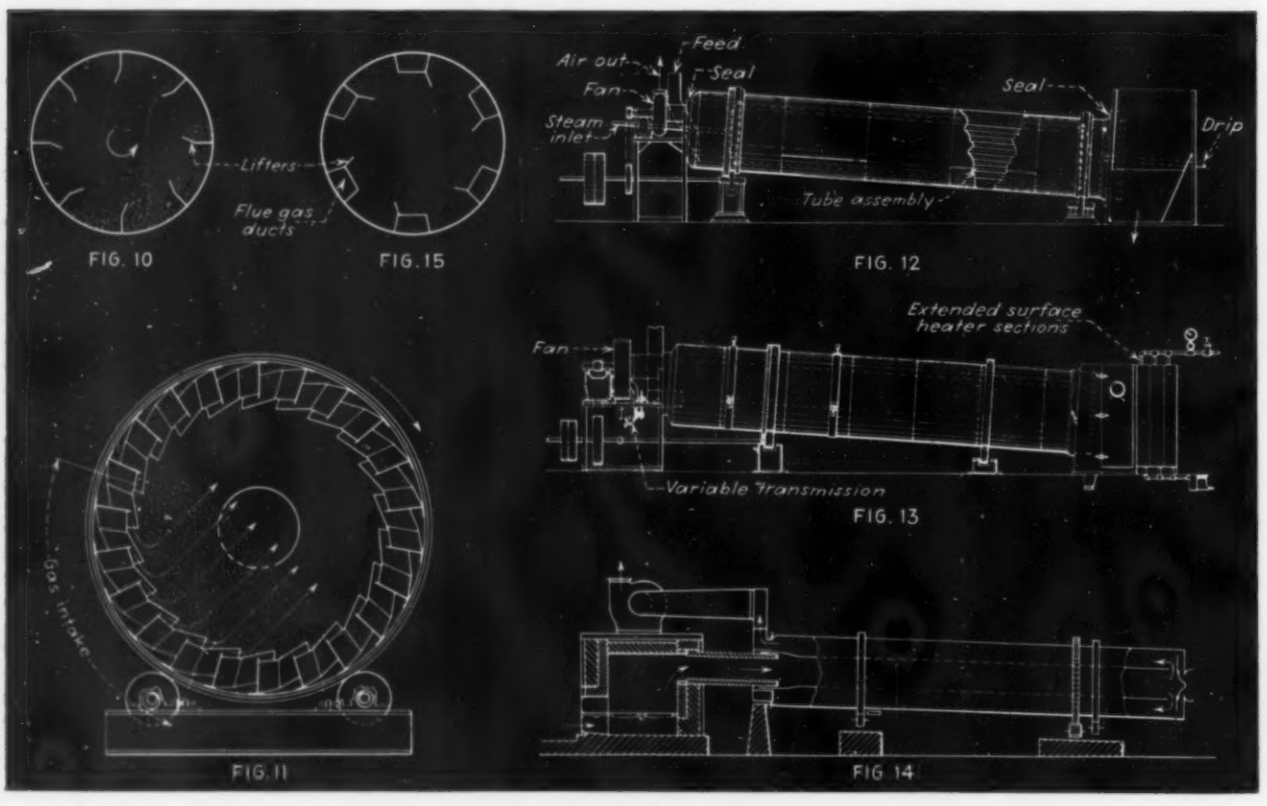
Through Circulation Dryers—Two special types of dryer employing the idea of the mesh belt have been developed to such an extent that they should be mentioned separately.

The first of these is the Aeroform dryer, Fig. 5, a development of Proctor & Schwartz. The tunnel dryer portion of this equipment is not unusual, consisting simply of a tunnel-like structure containing a continuous mesh belt, with provision for heating and recirculating the air in a number of zones, and arrangement of the fans so that the air may be passed either upward or downward through the material, as desired. The unusual feature of this dryer lies in the method of preparation of the material. This dryer is intended primarily for the handling of filter cakes and other sticky materials which ordinarily would be unsuited to through circulation. Such substances must first be subdivided into small sticks, cylinders, particles or granules by a preforming operation. With some classes of materials, the wet solid enters the dryer direct from the preforming process. In other cases, however, it is necessary to partially predry the material before it enters the main dryer.

Consequently, several methods have been developed for pretreatment. Materials which do not require predrying may be extruded through a perforated plate by means of a rotary or rolling extruder; they may be granulated through a screen of proper mesh size; or they may be formed into briquettes. For materials which must be predried, the usual method is to employ as the first drying stage a special type of drum dryer having a grooved surface. As the steam-heated drum rotates, material is forced into the grooves and then after partial drying, is removed from the grooves and broken into short sticks by means of comb-like fingers which scrape the material from the grooves. A third method which is occasionally used is to flake the material by solidifying on a chilled flaking drum.

Marshall and Hougen (*Trans. Am. Inst. Chem. Eng.*, **38**, 91, 1942) have discussed the application and characteristics of through circulation drying at considerable length. They find that granular, lump, flaky, fibrous and similar materials forming a permeable bed are suitable for this method of drying without special preparation. Such materials include silica gel, aluminum hydrate, granular cellulose acetate, open textile stock, charcoal, straw, and similar substances. They list as materials requiring preforming, those with enough water to form a homogeneous mass, as in filter cakes. Some materials of this class can be preformed without predrying. Others contain such a percentage of water that the material will flow under its own weight and hence will require predrying. Materials in this class include lead oxide, zinc oxide, titanium dioxide, and pigments in general, as well as many other chemicals.

(10) Typical rotary dryer cross section showing lifters; (11) Cross section of Rotary Louver dryer; (12) Steam tube rotary dryer gives high capacity at relatively low temperature; (13) Rotary indirect dryer with outside air heating; (14) Reverse current rotary dryer with central tube; (15) Cross section of reverse current dryer with peripheral heating tubes



A second type of dryer employing through circulation is a specialized variety known as the DLO, and developed by Oliver United Filters. This dryer is an adaptation of the Dwight-Lloyd sintering machine. The conveyor bed consists of a series of perforated pallets carried through the dryer by continuous chains. Lump or granular material placed on the pallets is thus carried through the drying zone, meanwhile being subjected to the downward action of hot air or combustion gases, traveling at high velocity. The high velocity is stated to remove considerable water mechanically by blowing it from the surface of the solid, thus making possible a considerably higher heat efficiency than would be possible if all the water were evaporated. The method is similar in this respect to that of drying on rotary vacuum filters.

Filter Dryers—Combination equipment, capable of performing two or more different operations has always intrigued the designer. First attempts at drying on rotary vacuum filters were made with the salt type, according to Barnebl (*Chem. & Met.*, July 1941, p. 80). These were not entirely successful and drying is now limited to the top-feed type which was designed for coarsely granular materials, can handle a very high feed density, and is capable of drying thoroughly at fairly good thermal efficiency. Wet material is fed through a hopper near the top of the drum. After one or more washes the material is dried on the drum by hot air sucked through the cake from a hood surrounding the drum. Since material dries from the outside, one or more scrapers before the final scraper may be used to remove the already dried material.

Festoon Dryers—Festoon dryers, properly speaking, are employed for the handling of web materials such as roofing paper and textiles, as in Fig. 6. On the other hand, a variation of this type is employed in the handling of pasty materials such as filter cakes. The method is to force the pasty material into an open mesh screen and then carry the screen containing the solids through the dryer either in loops or festoons. The festoon dryer for sheet and web materials in its simplest form consists of a tunnel-like inclosure containing a pair of parallel conveyor chains which support and carry through the dryer the sticks on which the material is looped. Owing to the possibility of stick marks on the material, a variation of this idea employs a series of supported rolls alternating with floating rolls on which the web is formed into loops (see Fig. 6). The upper rolls are carried on the conveyor chains and rotate very slowly as the chains move the rolls through the dryer. The floating rolls are supported in the bottoms of the loops of material and serve to maintain sufficient tension for proper operation. Since the rolls do not remain in contact with any particular part of the web, stick marks are impossible.

Pan Dryers—Many types of tunnel dryers employ pans for carrying loose granular materials which cannot be supported properly on a mesh belt. Many ingenious mechanisms have been developed for carrying pans through a dryer tunnel. In most cases the pans are arranged to make several passes back and forth within the dryer and thus reduce the necessary dryer length to a fraction of that otherwise required. In one design the pans are non-tilting, but instead are carried horizontally from pass to pass without discharging their material until the last pass has been completed. In another design tilting pans are employed which dump their material at the end of each pass to the next lower pass which travels in the opposite direction. In still another design of exceptionally large holding capacity (Fig. 7), the pans are tilted at an angle less than the angle of repose of the material, and overlap each other, thus carrying several times as much material per pass as if the pans were flat and not overlapping. At the end of each pass the pans dump their material to the reverse side of the pans of the next lower pass.

Vibrator Dryers—One type of tunnel dryer which partakes of the characteristics of the solid-belt dryer but offers an opportunity for contact heat transfer in addition to transfer from the drying air, is the vibrating conveyor dryer. The conveyor bed is vibrated electrically with a forward throw which advances the material through the dryer. In some dryers of this type, a heating medium is introduced in a jacket attached to the lower side of the conveying surface, thus permitting contact heating, in which case the drying air may not be heated.

Tower Dryers—Several special types of dryer partake of the characteristics of the tunnel dryer, although none of them may properly be described as tunnels. A very old type which is still suitable for the handling of many granular, non-caking materials, is the baffled tower or chimney dryer of Fig. 8, which is sometimes used for such materials as coal and china clay. This dryer is simply a tower or chimney of rectangular construction and greater or lesser height, discharging to the atmosphere at the top and connected to a firebox at the bottom. The chimney contains a number of sloping baffles, in staggered arrangement, alternating from two sides of the chimney. Solid material fed in the top slides down the first baffle and off the side, striking the second baffle and repeating the process, until it eventually discharges at the bottom. This dryer offers little opportunity for control but has been employed successfully on non-sensitive materials.

Turbo Dryers—The Turbo dryer, so-called because it employs a centrally located turbo-vane fan of large size, is made in several variations depending on the type of material to be handled. In none of these variations does the dryer resemble a tunnel dryer, although it possesses tunnel dryer characteristics. Perhaps the best general description of the Turbo type is that it is a tunnel dryer, rolled up into either a cylinder or a spiral, with special means provided to reheat the drying air a large number of times before it is discharged. This reduces the air needed to the amount required to carry out the moisture, and minimizes the temperature rise of both the exit air and the material.

In one form, known as the vertical, rotary shelf type, developed for the handling of crystalline, powdery and pasty materials, the equipment consists of a vertical cylindrical casing, as in Fig. 9, within which are a number of annular hearths consisting of individual trays, located one over the other in staggered arrangement. Outside these rotating hearths are the heating coils. In the center space is a vertical shaft carrying several fan wheels of special design to circulate the air. Entering material is fed through an opening in the roof, on to the topmost hearth. When one revolution has been completed, but before a tray reaches the feed opening, the material is scraped off to the next lower hearth through the gap between trays. Material then revolves on each lower hearth until the last one dumps it to the discharge. The method of circulation is such that air is drawn across the material, then picked up by the fan and returned to the heating coils, then blown again across the material, gradually advancing from the air intake to the discharge in a sort of spiral motion.

In another form of Turbo, adapted to the drying of web materials, the dryer consists of a horizontal cylindrical casing within which is a conveying drum mounted on a horizontal shaft. Outside the drum are the air-heating steam coils and inside the drum is a fan wheel of special design. As the web travels through the dryer on the drum, the air passes across the web, then through the steam coils, then through the fan, progressing around the periphery of the drum in spiral fashion so that it is reheated many times before being discharged in nearly saturated condition.

ROTARY DRYERS

Fully as important in the field of chemical engineering as the tunnel dryers are the rotaries, which are suitable for practically all dispersible materials, except those which tend to agglomerate or form balls or rings in the dryer. Rotary dryers are fundamentally through circulation machines, although they are not ordinarily so

regarded. Two different methods of obtaining through circulation are employed. The more common one (Fig. 10) is to lift the material with lifters attached inside the shell, and then dump it through the stream of drying air or hot gas. In the second method which requires no lifting and dropping, the shell has a special louvered surface (Fig. 11) which permits through passage of the drying gas.

The rotary dryer is a cylinder which is long compared with its diameter, carried on circumferential tires and wheels like a rotary kiln, and sloped to cause material travel. Starting with this elemental structure, such dryers branch out into several different constructions depending on whether hot air or combustion gas is used as the drying medium, and whether the contact between material and drying gas is direct or indirect.

Indirect Rotary Dryers—Perhaps the simplest form of indirect rotary mounts the tubular dryer shell within a masonry casing which is part of the firebox. The shell projects from the firebox at either end. Heat transfer is from the hot gases, through the shell, to the material. As with other indirect dryers, it is necessary to have a fan for passing air through the dryer shell. Several types of indirect rotary dryer employ hot air heated by steam coils or extended surface heat transfer elements. In one type (Fig. 12), a bundle of steam tubes is supported along the central axis of the cylinder and the material to be dried is lifted by cleats on the cylinder wall and showered through and against the steam tubes. In another type the air is heated outside the dryer and blown through in contact with the material, as in Fig. 13.

In another type of indirect dryer employing flue gases as the heating medium, the gases pass through a single central tube, or alternately through a number of centrally located tubes connected to manifolds at either end.

Direct Rotary Dryers—For the drying of materials which are relatively insensitive to heat and are not damaged by contact with flue gases, the direct dryer is used. Both the hot flue gases and the material pass through the shell. Sometimes, if an adequate chimney is available, no fan is needed but more commonly draft is supplied to an oil-, gas- or coal-fired furnace by means of an induced draft fan. Recirculation of a part of the gas is sometimes employed to control the temperature and humidity.

Reverse Rotary Dryers—The reverse, or indirect-direct, rotary dryer of Fig. 14 is the type used for highest heat transfer efficiency in the drying of materials which are not damaged by contact with flue gases. In the most usual type of construction, this dryer consists of two concentric shells, the inner shell serving as a flue for the first pass of the flue gases, and the space between the inner and outer shells serving for the second pass. Material travels through the space between the shells. In common with other rotary dryers, lifters of one type or another are provided for showering the material through the gas stream. Owing to the fact that both indirect heat transfer through the central shell and direct transfer by contact between material and gas are obtained, this type of dryer has an extremely high thermal capacity. One factor contributing to this is the reduction in radiation from the outer shell due to its lower temperature.

Another construction used in reverse rotaries, illustrated in Fig. 15, employs a shell on the inner surface of which are several box-like flues through which the gases make the first pass, then return through the shell.

Rotary Louver Dryer—A special type of rotary machine known as the Rotary Louver dryer has been manufactured for a number of years both abroad and in the United States. The shell proper is double-walled, as shown in Fig. 11, and consists of an outer cylindrical wall, within which is an inner, broken wall consisting of overlapping leaves, running the length of the cylinder, and serving as louvers for passage of the gas. This type of dryer has no lifters and the material simply rolls over and over as it spirals toward the discharge, the direction of rotation being such that material slides across the louvers, away from their openings. The stationary end plate at the gas entrance is constructed in a manner roughly similar to the surface vacuum valve of a rotary filter. The several openings around the periphery of the shell which connect with the louver spaces contact this valve surface. The circumferential length of the valve opening and its position with respect to the rotation of the dryer are so chosen that only those louvers which are covered by the drying material during the rotation of the dryer are connected to the gas inlet valve. In this manner, hot gas entering the louvers passes upward through the material, and then leaves the dryer through the center space.

DRUM DRYERS

Drum dryers are adapted to the handling of slurries and solutions. They are used for both atmospheric and vacuum drying and are built in several variations, including both one- and two-drum types. In any case, the drum consists of a hollow metal shell with a highly polished surface, the heating medium entering the shell through one of the trunnions, while the condensate is usually removed through the other. The drum is rotated at a rate dependent on the drying characteristics of the material, in contact with a doctor knife which continuously removes the dried material. The principal variations in such dryers arise from the method of feeding.

In single-drum dryers, which are particularly adapted to the handling of sticky materials, several feed methods are employed including dip, splash, pan, weir and slurry feeds. An inherent disadvantage of the single-drum dryer, as pointed out by Harcourt (*Chem. & Met.*, April 1938, p. 179) is that in obtaining the same drying surface as in a double-drum dryer, it is necessary to go to a larger diameter which immediately limits the steam pressure that can be used.

Double-drum dryers are of two types: When the drums rotate toward each other, as viewed from the upper side, they are referred to as double-drum dryers. When the drums rotate away from each other, they are referred to as twin-drum dryers. The ordinary double-drum dryer of Fig. 16 makes use of what is known as a trough feed. Its two drums are substantially in contact along an element of their peripheries. Through the use of end boards, the upper surfaces of the two drums form a trough in which the feed material is placed. As the drums rotate, a coating of material adheres to their surfaces and is scraped off by a doctor knife after a rotation of about 220 deg. from the contacting point.

Certain difficulties encountered with atmospheric double-drum dryers resulted in the development of the twin-drum type. Accumulations of material on the end boards could be prevented, it was reasoned, by eliminating the end boards. The twin-drum dryer, consequently, is essentially similar to two single-drum dryers operating from a single feed trough placed beneath the drums. The feed is accomplished by dipping the drums into the feed material, or splashing it on the lower surface of the drums. For some applications, trough feed similar to the ordinary double-drum dryer may be used satisfactorily. The trough-feed twin-drum dryer inherently has extremely large capacity. Consequently it is sometimes used as a predryer in conjunction with a continuous rotary machine. It is able to produce a high capacity of coarse granular material which is dry enough for rotary dryer feed.

Vacuum Drum Dryers—For the drying of solutions and fluid slurries which must be handled at extremely low temperatures, the vacuum drum dryer has been employed to a considerable extent. This machine is essentially similar to the atmospheric single-drum dryer, except that it is inclosed in an evacuated casing and requires special methods for discharge of the dried material. In these dryers the product is scraped from the drum and delivered by a screw conveyor into a receiver. Generally the machine is supplied with two receivers so that the vacuum may be broken in one, for discharge of the material, while the other is being filled.

Can Dryers—Such dryers are in many

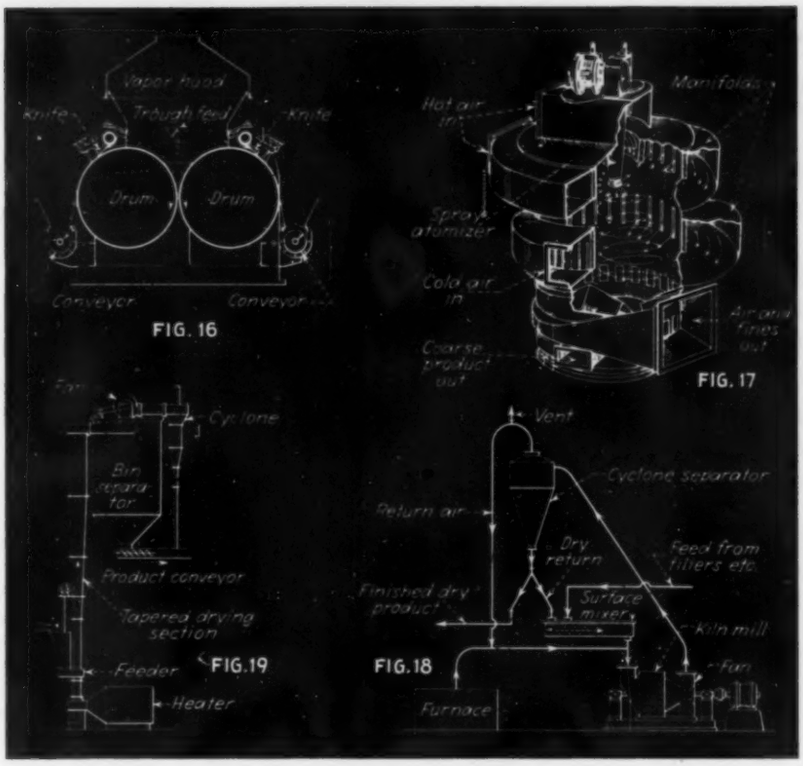


FIG. 16

FIG. 17

FIG. 19

FIG. 18

(16) Common type of double drum dryer for liquids and suspensions, showing trough feed; (17) Bowen spray dryer with turbine type atomizer and product cooling; (18) Raymond kiln mill or flash dryer; (19) Trump Vertex dryer

ways comparable to drum dryers, with the exception that they are intended for the handling of web materials and consequently require no special feed mechanism or doctor knife. They are used largely on paper machines and for the drying of such materials as cellophane and textiles. A typical dryer consists of a large number of steam-heated cylinders, closely spaced, three or four high, so as to obtain the maximum possible surface in a given volume. Arrangement of the cylinders is such that the contact area of the web on the cylinder surface is considerably over 180 deg. Dryers of this type inherently do not lend themselves to the best possible air circulation, nor to vacuum operation, although considerable work has been done, particularly on paper machine dryers, to improve the thermal efficiency and output per square foot of heating surface. One form of paper machine dryer, for example, operates under a partial vacuum to increase capacity.

SUSPENSION DRYERS

In several types of dryers the method of drying in suspension in a current of hot air or flue gas has been employed to give extremely high capacity and such rapid drying that the solid scarcely attains a temperature higher than that of the wet bulb. This permits the handling of even delicate materials with high temperature drying media.

Spray Dryers—The most common of these is the spray dryer which is used for solutions and suspensions. Designs vary in a number of respects, principally in the method of producing the spray, in the means of circulating the heated drying medium, and in the method of collecting the material. An inherent advantage of the spray dryer is its ability to pass from liquid to dry solid in a single step, but at a thermal efficiency somewhat lower than is obtainable by combinations of evaporators and other dryer types. Another advantage is ability to produce the final product in a desirable spherical form. A disadvantage is that with most products relatively elaborate dust collection equipment is necessary. A typical design appears in Fig. 17.

Spray dryers operating on materials in the low viscosity range generally employ pump pressure and spray nozzles for the production of spray. For slurries and suspensions, and liquids of higher viscosities, the most common dispersing means is a high-speed turbine wheel which breaks the material down into extremely fine particles and discharges it horizontally in all directions from the wheel. Spray dryers customarily employ tangential circulation of the drying medium. The hot air or flue gas usually enters the cylindrical dryer shell at about the level of the spray, then spirals downward toward the discharge. In some designs coarser material is collected in the bottom of the dryer chamber and discharged by a scraper mechanism. In others, the entire output is swept from the dryer chamber and collected in dust collectors. Dust collection equipment for such dryers includes large-diameter cyclones, multiple small-diameter cyclones, and bag type filters. Numerous materials are being handled on spray dryers ranging from milk and latex to relatively thick slurries and homogeneous materials such as soap.

Flash Dryer—Similar advantages to those of the spray dryer are obtained in other suspension dryer designs. One type, known as the kiln mill or flash dryer (Fig. 18), employs a combination of furnace, hammermill, air or flue gas circulating system and dust collection equipment. This dryer dries and grinds simultaneously. Materials handled range from sticky filter cakes to non-adherent crystalline slurries. In handling some sticky materials which would not pass satisfactorily through the hammermill, it is customary to recirculate a part of the previously dried material, which is mixed with the incoming feed in a pug mill. In dryers of this type, the feed is first disintegrated in the hammermill and then swept out in suspension in the hot gases. The dried material is collected in a large diameter cyclone, with either multiple cyclones or a bag filter for the fines. Part of the drying air may be recirculated.

Dispersion Dryer—A type somewhat similar to the flash dryer is called the dispersion dryer. A fan-like "dispersing machine" is employed instead of a hammermill. This type was designed for the drying of wet materials ranging from filter and centrifugal cakes to slimes, pulps and other colloids which cannot be filtered. The wet material is first mixed with partially dried material, or in some cases with completely dried material. It is then dried in agitated suspension in a hot stream of air or combustion gases. Partially dried material is separated from that which has been completely dried by an impact separator, for mixing with the feed. The completely dried material is collected in a multi-cyclone separator and bag filter. Exceptionally high thermal efficiencies are claimed, with heat requirements ranging from 1,600 to 2,500 B.t.u. per lb. of water evaporated.

Vertex Dryer—Another type of suspension dryer, known as the Trump Vertex, consists essentially of a vertical tube, the diameter of which increases from bottom to top. The heated drying air or combustion gas passes through the tube, as in Fig. 19. Particles of wet material are fed into the gas stream at a point near the bottom and are carried upward until they reach a level where their falling rate equals that of the upward flow rate of the gas. As the material is dried, it loses weight and consequently balances at a higher level. When the material has been fully dried, it is

carried out of the vertical tube and collected in suitable collection equipment. As in the case of other suspension dryers, the fact that particles are able to dry from all sides results in exceptionally high drying rates, with ability to maintain the temperature of delicate materials at substantially the wet bulb. An advantage claimed for this dryer which seems to be obtainable with no other type is the automatic ejection of the material from the dryer when the desired degree of moisture removal has been obtained. This feature, however, presumes a steady flow of air, and a uniform density and size of particles.

ELECTRIC HEAT

If desired, of course, electricity can be used for almost all kinds of drying, either as a means of heating the drying air, or in heating the material by contact or radiation. However, there are a number of special electrical heating methods which should be mentioned here.

Infra Red Heating—Within the last few years, the use of special infra-red radiation-producing incandescent bulbs for heating and drying has become quite common. The method was developed primarily for the baking of lacquers and other finishes. A secondary application in which there is considerable current interest is in the drying of a variety of chemicals. The obvious advantages to be gained by drying with radiations from low-temperature incandescent filaments arise from two characteristics of such radiations. In the first place, infra-red radiations can be directed by means of reflectors and heat loss to the dryer structure can be largely avoided by this means. In the second place, radiant heat transfer to and from gases is a decidedly inefficient operation, and therefore the radiant heat distributes itself largely to the drying material, with only a slight temperature rise in the drying air, thus giving good thermal efficiency and an operating cost comparable with other methods.

Two new drying methods employing electricity are still largely in the experimental stage but can be mentioned. One is the use of a rapidly alternating electrostatic field to produce heat within materials of nonconducting nature. The other method is the use of extremely short radio wave lengths. This method, which operates on the principle of the General Electric "fever machine," is understood to have been applied recently to drying. Similar to the electrostatic method, the heat is produced directly within the material. Compared with present methods of drying, presumably these new methods will have the advantage of avoiding difficulty in transferring heat within materials which are good heat insulators, or which inhibit diffusion of moisture to the outside.

Absorption Theory and Design Calculations

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Development of the diffusional aspect of absorption has been carried farther, in all probability, than that of any other unit operation. Mr. Scheibel's familiarity with the subject enables him to bring together much of this work, appraise and digest it, and present it so as to facilitate assimilation. The practice and equipment phases of absorption are treated in another article, on page 107.—*Editors.*

ABSORPTION generally involves a transfer of material from a gaseous mixture to a liquid solution. The process can be applied to remove the last traces of an undesirable compound from a useful gas, or to recover a valuable compound present in dilute quantities in a waste gas. Besides these purification operations, however, absorption can be applied through the use of a proper selective solvent to effect the separation of a mixture which could not be separated by ordinary methods of distillation.

The reverse operation, namely, the transfer of a material from a liquid solution to a gaseous mixture, is called desorption. This operation can be used to remove the last traces of more volatile material from a solution, a common example of which is steam stripping such as is applied to the side-streams from a distillation tower for crude petroleum; and it is also frequently used to remove a dissolved gas from a solution. Spray ponds and cooling towers are also special types of desorption equipment.

In order to design equipment for this operation, a fundamental basis must be devised, upon which the preliminary experimental data obtained on small-scale equipment can be reliably transposed, to predict the operation of larger equipment. To accomplish this result, it is necessary to consider the effect of the different factors in the design, so that the limitations of the basic data will be understood. The purpose of this paper is to present a brief yet fairly comprehensive outline of the methods available for the study of experimental data and the subsequent design of commercial equipment. Also, the various factors which have not as yet been fully investigated are mentioned from the point of view of qualitative results anticipated and observed.

There are three types of tower usually employed for absorption—plate, packed, and spray towers. One obvious factor in absorption is the amount of contact surface available. In plate towers this is more or less fixed by the design of the bubble caps, and is not very greatly affected by varying rates of flow. Similarly, in spray towers, the amount of contact surface is controlled by the size of the droplets issuing from the spray nozzle. Packed towers show an interesting correlation between the surface of contact and the pressure drop in the packing. At exceptionally low liquid rates in packed towers there is a tendency toward "channeling" in the packing, with resulting reduction in the effective surface of contact. Towers should never be designed for these rates. Instead either a smaller tower should be used or scrubbing liquid re-cycled.

The best operation of packed towers is realized where the liquid flows over all the packing at as uniform a rate as possible. This occurs below the "loading" velocity where the liquid is considered as flowing freely over the packing. The loading velocity is indicated by a variation in the relation between the pressure drop in the packing and the gas velocity. Below this velocity the pressure drop varies approximately as the 1.8 power of the gas velocity. The point at which the power relation increases from 1.8 to a higher power, above 2, is the "loading velocity," as defined by White[2].

Above this velocity the liquid does not flow freely from the packing, and the change in the pressure drop variation is accompanied by an increase in the liquid retention or "hold-up" of the packing. The liquid retained fills up many of the interstices of the packing and thus decreases the surface of contact between the phases. Hence, the amount of material transferred also decreases at the loading point. As the liquid flow rate in the tower is still further increased, a point is reached where this large quantity of liquid can no longer flow out of the tower. At this point, the pressure drop in the column tends to increase with gas rate even more rapidly as it approaches the hydrostatic head of the liquid filling the column. This point is accompanied also by the appearance of entrained liquid in the overhead gas stream since,

Nomenclature

a = Effective interfacial area, sq.ft. per cu.ft.
c = Concentration.
c_B = Concentration of inert material in the film.
c_{BM} = Log mean concentration of inert material in film.
C = Concentration, pound moles per cu.ft.
D = Diffusivity constant.
G = Gas rate, pounds per hr. and sq.ft. of column cross section.
H = Henry's constant.
k = Coefficient of mass transfer.
k_G = Coefficient of gas film, pound moles per hr., sq.ft. and atm.
k_L = Coefficient of liquid film, pound moles per hr., sq.ft. and conc. diff. of 1 mole per cu.ft.
K_G = Overall coefficient based on gas concentrations, same units as k_G.
K_L = Overall coefficient based on liquid concentrations, same units as k_L.
L = Liquid rate, pounds per hr. and sq.ft. of column cross section.
L_m = Liquid rate, pound moles per hr.
l = Packing height, ft.
M_B = Molecular weight of inert gas.
dn = Differential quantity of material absorbed.
N_A = Amount of material absorbed, pound moles per hr. and cu. ft. of packing.
N_T = Number of transfer units = $\int dy/(y-y^*)$.
P = Total pressure in column, atm.
p = Partial pressure of solute, atm.
t = Time.
x = Liquid concentrations, mole fractions.
y = Vapor concentration, mole fraction.
Δy_m = Mean driving force.
y^* = Equilibrium pressure of liquid of composition x.
z = Distance across gas or liquid film.
$\alpha, \beta, \gamma, \epsilon, \eta$ = constants to be evaluated.

Note: Subscripts G, L and i refer respectively to conditions in the body of the gas, in body of liquid, or at interface.

as the liquid can no longer run out the bottom of the column as fast as it is fed in, it must overflow at the top.

The rate producing this condition is called the "flooding velocity," above which no tower can be effectively operated. Obviously, loading and flooding velocities are important in the design of packed towers, and a knowledge of the pressure drop characteristics is necessary in design, not only in considering fan power requirements, but also, in determining the limiting conditions for efficient mass transfer. A general correlation of the flooding velocities, based on the different properties of the packing, and the gas and liquid streams, has been presented by Sherwood, Shipley and Holloway,[11] but as yet a general correlation of loading velocity is not available.

It would appear that a fairly straightforward and direct approach should be possible for such a simple problem in diffusion as the transfer of material from a gas to a liquid solution. Unfortunately, so many other factors enter into the situation that at present much work is still to be done in the general correlation of data.

The study of diffusion was developed from the kinetic theory, and was used to prove the theory. Like heat transfer, the mathematical solution of diffusional problems is far ahead of the physical treatment.

One of the original concepts of diffusion is Fick's Law:

$$dn = Da \frac{dc}{dz} dt \qquad (1)$$

which states that dn, the quantity of material diffusing in a sertain direction z through an area a at right angles to this direction, is proportional to the time dt, the area a, and the concentration gradient in the direction of diffusion $\frac{dc}{dz}$. In this formula, D is the proportionality constant and is a reciprocal measure of the resistance to diffusion. The kinetic theory of gases indicates that this resistance is not a constant, but is proportional to the concentration of the inert material, c_B, in the film through which the material must diffuse. Thus, we may write:

$$\frac{dn}{dt} = \frac{ka}{c_B} \frac{dc}{dz} \qquad (2)$$

where D has been replaced by the more fundamental value of k/c_B. In the case of steady state diffusion of one component through a film of thickness dz, the value of c_B at any point in the film is equal to the total concentration, less the value of c. Integrating this formula across a definite film of thickness z, with a concentration of c_1 on one side and c_2 on the other, it can be shown that:

$$N_A = \frac{ka}{zc_{BM}} (c_1 - c_2) \qquad (3)$$

where c_{BM} is the log mean concentration of the inert material in the film, and N_A is the amount of material transferred per unit time.

Most problems in absorption involve fairly dilute mixtures and solutions, so the value of c_{BM} is substantially constant. Furthermore, for a given absorption system we can assume that the film thickness is a constant. Thus we have the more familiar formulas:

$$N_A = k_L a (c_1 - c_2) \qquad (4)$$

and

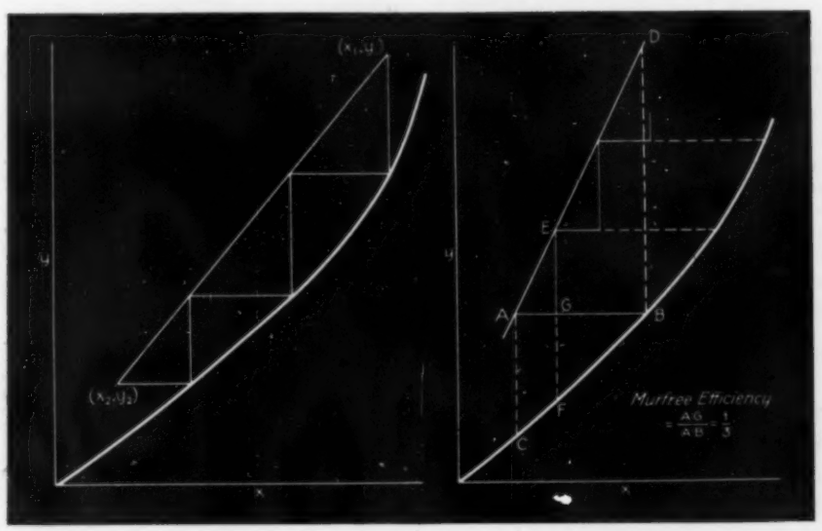
$$N_A = k_G a (p_1 - p_2) \qquad (5)$$

The first formula expresses the rate of transfer through a liquid film and the second, through a gas film. The units of the constants k_L and k_G must be consistent to make the equations dimensionless, and it must be remembered that the values of k_L and k_G will be constant only if the film thickness and the log mean concentration of the inert material in the film are constant.

Most of the experimental work on absorption has been carried out on packed towers and plate towers. For the design of plate towers the concept of the theoretical plate was conceived, analogous to the theoretical plate used in design of distillation equipment. The method of determining the number of theoretical plates in an absorption system is similar to the McCabe-Thiele method for distillation (Fig. 11). The equilibrium curve for the system is drawn with x as the concentration in the liquid phase and y as the concentration in the gas phase. The operating line, which may be assumed to be straight in the dilute region, is then drawn, and the number of trays stepped off, similar to the McCabe-Thiele method. When the number of theoret-

Fig. 1—Application of McCabe-Thiele method to determination of number of theoretical plates in an absorption system

Fig. 2—Diagram illustrating the difference between theoretical plates and plates determined by the method of the Murphree efficiency



ical plates in a system has been so determined, the actual number of plates necessary to accomplish the job is found by dividing the number of theoretical trays by an all-inclusive factor called "plate efficiency." In the case of distillation, this "plate efficiency" varies between 65 and 100 per cent. However, in absorption, the plate efficiencies reported vary from 7 to 100 percent, with 25 as a usually probable figure.

The factor of "plate efficiency" as such is decidedly vague. Also, it gives a different answer when used as the overall efficiency, as compared with the result when the same efficiency is used as an individual plate efficiency. In the latter case it is referred to as a Murphree efficiency[6]. The Murphree efficiency is derived from a consideration of the rate of mass transfer between the phases, and thus gives a clearer concept of the exact action occurring on a plate tower.

When all the factors are considered, the theoretical plate cannot be an actual possibility, since it would mean that the vapor leaving the plate was in equilibrium with the liquid, and hence there could be no concentration difference to absorb the last amount of solute. This would require an infinite coefficient of absorption. A reported tray efficiency of 100 per cent means that the actual efficiency is so close to 100 per cent that the difference cannot be measured, but this difference nevertheless must exist.

The reason for the difference between the Murphree efficiency and the overall efficiency is easily seen from Fig. 2, in which the driving force across the single plate AB varies between AC and DB. On the other hand, if the line representing the Murphree efficiency of the plate is drawn, the driving force varies between AC and EF. The situation is thus seen to be approaching the concept of the transfer unit, as derived by Chilton and Colburn[3] for the design of packed towers where the liquid and gas composition change continuously.

TRANSFER UNIT

The purpose of the transfer unit is to define a measure of conductivity (which is comparable to that in electricity), where conductivity equals:

$$\frac{1}{\text{resistance}} = \frac{1}{\dfrac{\text{driving force}}{\text{quantity transferred}}}$$

Thus, the conductivity is equal to the quantity of material transferred, divided by the driving force. Consider that the transfer of a differential quantity of material changes the concentration of the gas stream by an amount dy, which changes the concentration of the liquid stream by dx. Since the two quantities transferred must be equal, $Vdy = L_m\,dx$, and dy/dx, which is the slope of the operating line, is equal to L_m/V.

Thus, the value of $Vdy/(y - y^*)$ is a measure of the conductivity of the system, where y^* is the equilibrium back-pressure of the solution and $y - y^*$ is the driving force causing the material to be transferred. A measure of the total conductivity of the system may be obtained by integrating, since V is assumed constant, and this may be set equal to the conductivity of the entire system, expressed as a function of the total material transferred and some suitably determined mean driving force, Δy_m:

$$V\int_{y_2}^{y_1}\frac{dy}{y-y^*} = \frac{V(y_1-y_2)}{\Delta y_m}$$

whence the mean driving force is:

$$\Delta y_m = (y_1 - y_2) \div \int_{y_2}^{y_1}\frac{dy}{y-y^*} \qquad (6)$$

In the plate method of evaluating absorption systems, it can be seen that in effect the number of theoretical plates required is the number of times the mean driving force $y - y^*$ must be laid off to give the total increment in y from y_2 to y_1 (Fig. 1). Thus, the value of the integral, which has been defined by Chilton and Colburn as the number of transfer units, is

$$N_T = \int_{y_2}^{y_1}\frac{dy}{y-y^*} = \frac{y_1-y_2}{\Delta y_m} \qquad (7)$$

and is similar to the theoretical plate, except that a different average driving force is chosen to be laid off between y_1 and y_2. This average is exact for a series of differential steps; and since the tray efficiency of absorption towers is low, the more exact method of the Murphree efficiency, when applied to a plate tower, approaches the method of evaluating the transfer unit. Thus, it is possible to determine the number of transfer units in a system, and from this to calculate the number of transfer units equivalent to one plate, which would be a rapid method for estimating the Murphree efficiency at small values.

The applicability of the transfer unit to packed towers, in preference to the height of an equivalent plate is of course self-evident from the derivation. The relation between the transfer unit and the mass transfer coefficients may be seen by a consideration of Equation (5). In this formula, N_A may be taken as the quantity of material absorbed per unit time per unit volume of tower packing, if the term a is defined as the square feet of interfacial area per cubic foot of packing. This term bears no relation to the surface area of the dry packing and is therefore incorporated in the constant k_Ga, which varies with different packings. In all the following formulas the term k_Ga will be treated as a single constant which must be evaluated.

Since $p_1 = Py_1$ and $p_2 = Py_2$, from Equation (5):

$$N_A = k_Ga\,P\,(y_1 - y_2)$$

However, over the entire column a mean driving force is chosen, such that:

$$N_A = k_Ga P \Delta y_m \qquad (8)$$

Hence $k_Ga = N_A/P\Delta y_m$. Since $N_A = G(y_1 - y_2)/M_Bl$, by combining the last two expressions with Equation (6):

$$k_Ga = \frac{G}{M_BPl}\int_{y_2}^{y_1}\frac{dy}{y-y^*} \qquad (9)$$

where k_Ga = pound moles transferred per hr., cu.ft. of packing and atm.; G = pounds of inert gas per hr. and sq.ft. of column cross-section; M_B = molecular weight of the inert gas; P = total pressure in system in atmospheres; and l = height of the packing, in feet. The value of $\int dy/(y-y^*)$ is dimensionless, and Colburn has pointed out that it is a measure of the difficulty of separation of a definite system.

For the case of a straight equilibrium line, the log mean value of Δy_m may be substituted in Equation (8) to obtain k_Ga. However, most equilibrium lines are curved, and two methods have been recently proposed to evaluate the integral $\int dy/(y-y^*)$. One suggested by Colburn[3] has been mentioned by Duffey in another article in this issue (pp. 107-109.—Ed.). This method was applied by Othmer and the writer in calculating experimental absorption data taken on pilot plant equipment. A definite limitation was observed which was traceable to the original assumptions in the derivation[5]. Thus, the formula was found to be exceptionally accurate for the values of mV/L_m below 0.75, but as the value of this term approached and exceeded unity, the formula did not hold. A second method of evaluating this integral was therefore developed by Othmer and the present author[5] and this method is not subject to such restrictions and can be used with equal reliability over the entire range of conditions. It does not depend on the assumptions causing the inaccuracies of the first method.

One of the most useful concepts in the study of absorption equipment operation was the two-film theory proposed by Whitman in 1923[15]. This theory states that the resistance to diffusion is composed of a gas film and a liquid film in series, and that the concentrations at the interface between the two films are in equilibrium. Under steady-state conditions, where there is no building up of material in the films, the material transferred through each film must be equal.

From Equations (4) and (5)

$$N_A = k_La\,(C_i - C_L) = k_Ga\,(p_G - p_i)$$

where the subscripts i, L and G applied to the concentrations and partial pressures refer to the interface, main body of the liquid and main body of the gas, respectively. If Henry's law holds, then $C = Hp$ and

$$N_A = Hk_La\,(p_i - p_L) = k_Ga\,(p_G - p_i)$$

If now K_Ga is taken as an overall coefficient such that:

$$N_A = K_Ga\,(p_G - p_L) \qquad (10)$$

then:

$$K_Ga = \frac{1}{\dfrac{1}{k_Ga} + \dfrac{1}{Hk_La}} \qquad (11)$$

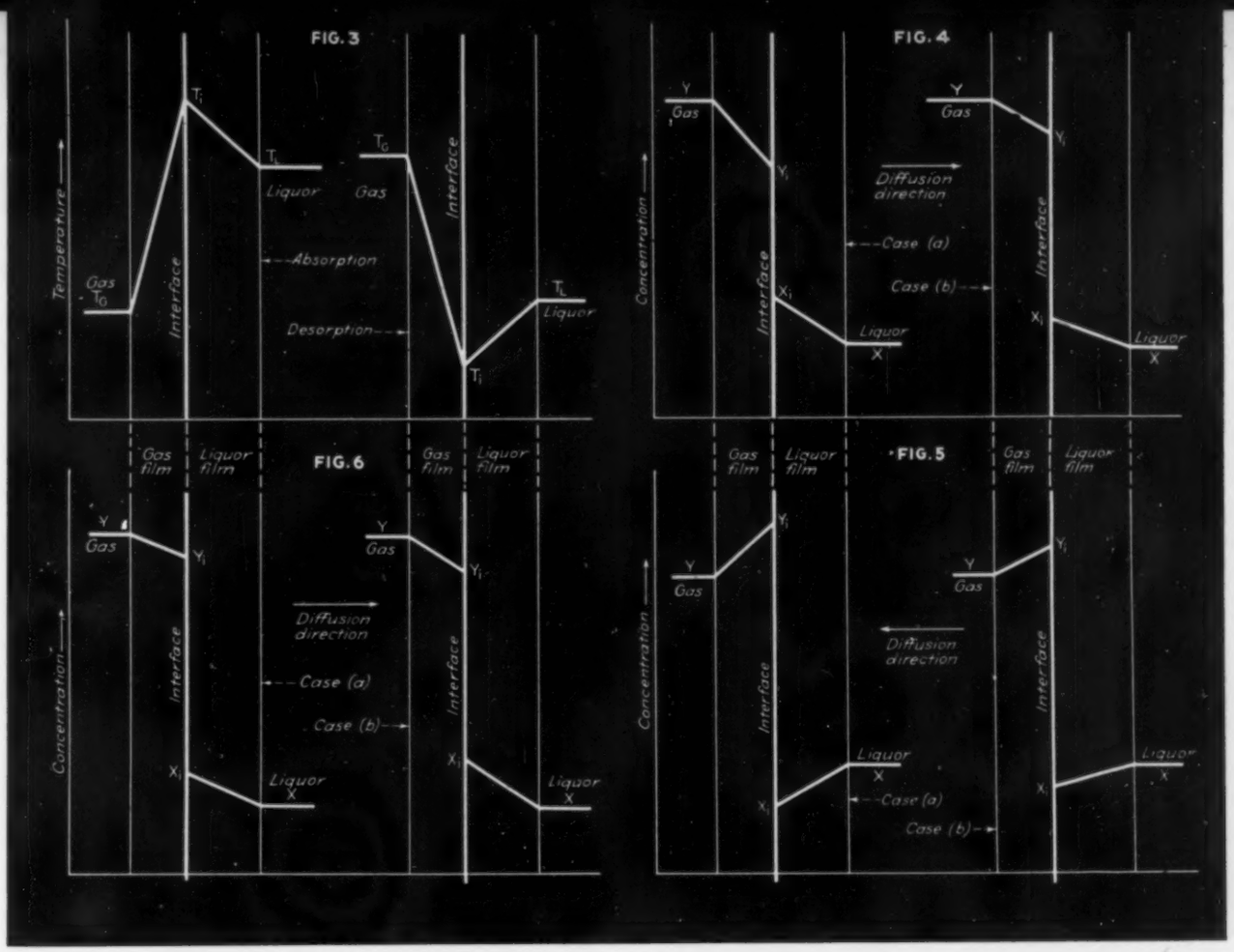


Fig. 3—Showing distribution of temperatures across the interface in cases of absorption and desorption

Fig. 4—Showing effect of heating at interface on driving forces across films in absorption; Case (a), interface equilibrium conditions based on liquor temperatures; Case (b), allowance made for heating at interface; equilibrium conditions based on true interface temperatures

Fig. 5—Showing effect of cooling at interface on driving forces across films in desorption; Case (a), interface equilibrium conditions based on liquor temperatures; Case (b), allowance made for cooling at interface; equilibrium conditions based on true interface temperatures

Fig. 6—Showing effect of cooling at interface on driving forces across films in absorption; Case (a), interface temperature assumed equal to main body liquor temperature; Case (b), allowance made for cooling at interface, with interface temperature less than liquor temperature

and similarly, if K_L is defined as:

$$N_A = K_L a\,(C_G - C_L) \qquad (12)$$

it can be shown that:

$$K_L a = \frac{1}{\frac{1}{k_L a} + \frac{H}{k_G a}} \qquad (13)$$

The original consideration of these formulas led to the conclusions that if a gas is very soluble in the solvent, so that H is large, the value of $1/Hk_La$ in Equation (11) is negligible. Therefore $K_Ga = k_Ga$ and the gas film is considered controlling. Conversely, if the gas is only slightly soluble in the solvent, H is small and the value of H/k_Ga in Equation (13) is negligible. Hence, $K_La = k_La$ and the liquid film is considered controlling. These assumptions presuppose that k_Ga and k_La are of the same order of magnitude, which is not borne out by present indications.

The only factors affecting the value of K_Ga in a given system, as previously derived, should be the log mean pressure of the inert gas and the thickness of the gas film. Heat transfer data indicate that the thickness of the gas film is proportional to the 0.8 power of the gas velocity. Thus, if the gas film is considered controlling, the overall transfer coefficient should be independent of the liquor rate and should vary as the 0.8 power of the gas rate. Thus, a plot of $1/K_Ga$ versus $1/G^{0.8}$ should be a straight line through the origin, with G as lb. gas per hr. and unit of column cross section. The most common highly soluble gas is ammonia, and the latest data on this system indicate that this is not the case. Liquid rate was found to have a definite effect on the coefficient.

Work on liquid film coefficients by Sherwood and Holloway[12] showed that, below the loading velocity, the transfer coefficients for oxygen in water (a purely liquid-film-controlling system with no inert gas present) was independent of gas velocity and varied as a power of the liquid velocity.

Thus, based on the assumption that the gas film coefficient is dependent solely on the gas rate and the liquid film coefficient is dependent solely upon the liquid rate, the overall transfer coefficients for a given system should correlate to the general formula:

$$K_Ga = \frac{1}{\gamma_G{}^{-0.8} + a_L{}^{\beta}} \qquad (14)$$

Most of the previous work on ammonia has been reported in the form:

$$K_Ga = \gamma G^{\eta} L^{\epsilon} \qquad (15)$$

However, the latest work by Dwyer and Dodge,[8] when recalculated by a new method developed by Othmer and the writer, was found to correlate equally well to both the above formulas. It is possible, therefore, that previous work could be similarly correlated in a general formula of the first form. Data on acetone absorption by water in a large column packed with 1-in. rings were also reported by the same authors[8] as correlating to this general formula. Additional as yet unpublished data obtained at the Polytechnic Institute of Brooklyn, on the same acetone and water system, using Stedman packing, also were found to correlate exceptionally well to this formula. Thus, it appears that even though the value of H is large (or small), the dependence of the overall coefficients on both the

gas and the liquid rate is such that both films must be considered in diffusion, except in special cases such as evaporation of pure liquids.

The exact variation of the transfer coefficients has not been established but an interesting feature of the two-film theory is that even though the values of $k_g a$ and $k_L a$ may actually be independent of temperature, the value of the overall coefficient $K_G a$ would decrease with increasing temperature, since H decreases with the temperature. Similarly $K_L a$ would increase with temperature.

Many other factors enter into the coefficients of transfer. The data of Sherwood and Holloway[11] showed that for the case of a true liquid-film resistance, the rate of transfer was constant with respect to gas rate up to the loading velocity, after which it increased rapidly. The same work showed that the coefficient of mass transfer increased as a definite function of the liquid rate to a power less than unity, whereas above the loading velocity it decreased. Further work at much higher liquid velocities confirmed these effects and showed that they were extremely pronounced.[4] One explanation for this decreasing rate of transfer at high liquid rates was that the rapidly down-flowing liquid entrained gas bubbles of partially denuded gas, and thus tended to dilute the gas at the bottom of the tower.

The effect of surface of contact between the phases has been previously discussed. The surface of the dry packing was found to have no relation to the coefficient of mass transfer under identical conditions. The smallest size packing would be expected to present the largest surface, whereas in a series of runs on Berl saddle packing of different sizes, Sherwood and Holloway[11] found that the 1-in. size gave coefficients greater than either the ½-in. or 1½-in. size. This indicates that there is not efficient circulation of the liquid over the smaller packings, probably due to surface tension of the liquid which causes it to fill up many of the interstices and remain there permanently, creating a large amount of "dead" volume and surface. It appears that for a definite set of liquid characteristics there is an optimum packing size.

The simplest case of mass transfer through a gas film is found in the evaporation of a pure solvent, such as the humidification of air with water. The temperature effects in more complex systems may be considered by analogy with this special case, which has been thoroughly studied. Fig. 3 shows the distribution of temperature across the interface. The minimum temperature at the interface, shown for desorption, has long been considered in regard to the conditions present at the bottom of a cooling tower. Thus, in absorption, where heat is liberated at the interface, the temperature might readily be a maximum at this point. The effect on the value of the transfer coefficient, based on assuming the interface temperature, was noticed by Walter and Sherwood[13] in some runs on humidification of air in a bubble-cap absorber. They found a 25 percent increase in the coefficients in the case where the interface temperature was higher than the main body liquid temperature. Thus the true driving force for humidification was larger than that used in the calculation of $K_G a$. From this it follows that the calculated value of the coefficient was larger than the true value based on the actual driving force.

The effect of the interface temperature can be easily seen from Fig. 4, where in absorption the interface temperature increases due to the liberation of heat. On this account the partial pressure of the solution at the interface will be larger, decreasing the value of $y - y_i$. Actually, the effect will be equalized as shown, in that y_i/x_i will be in the ratio prescribed by the temperature of the interface. This same effect takes place conversely in desorption, as shown in Fig. 5. The net effect of the interface temperature in both cases is to make the calculated values low. The writer has re-calculated the data of Dwyer and Dodge[5] according to the new method[9] previously mentioned, which has a distinct advantage over the log mean driving force used in the original paper. It was found that there is a definite increase in the coefficients of absorption of ammonia when the inlet air is unhumidified, compared with runs with humidified air. The evaporation of the water from humidified air, as has been shown, decreases the interface temperature (Fig. 6). This is the opposite temperature effect from that resulting from the normal absorption of ammonia, which is in agreement with the theory originally described by Walter and Sherwood.

Since most absorption or desorption operations are accompanied by relatively large heat effects, the measurement of the true coefficients is difficult. One method would be to determine the coefficients at low concentrations and extrapolate to zero concentrations; but such measurements require extremely precise determinations of small gas concentrations and are difficult to obtain. The previous discussion leads to the conclusion that the apparent coefficient of transfer decreases with large concentration differences. While the most important value from the design standpoint is this actual apparent coefficient, care should be taken not to extrapolate the coefficient excessively to large concentration differences (driving forces), beyond the limits of the data, without making some allowance, or introducing a safety factor. More work is necessary on this subject before we can predict the coefficient accurately over a wide range of conditions from a few data for a limited range.

Another major difficulty in determining transfer coefficients lies in the use of the proper equilibrium data. The work on acetone absorption previously mentioned was originally calculated on erroneous equilibrium data. When the error was rectified, the few runs that had previously been rejected as inconsistent were found to correlate, along with the others. Thus, the proper evaluation of equilibrium data is an important factor in absorption design. A method of correlating equilibrium data, previously proposed by Othmer[7], by plotting the partial pressures of the components of a system against the partial pressure of a related reference material at the same temperature, has been extended to the correlation of the solubilities of gases in solutions with equally good consistency.

A complete understanding of the mechanism and factors involved in an absorption problem is extremely desirable, since by this means it would be possible to calculate a reliable solution to the problem from only a few data, using interpolation or extrapolation. Several methods have been proposed but there is as yet no definite overall method which has been found useful in all cases, and estimates must therefore be made cautiously. However, if basic data are available in a similar or completely comparable system, the method outlined in this paper for the evaluation of the system can be applied with a high degree of accuracy.

The limiting factor in the design is not in the mathematical treatment of the problem, but in the basic physical data employed, and in their interpretation. Data derived from an identical system, of course, give the effective coefficients which are the desired values in all cases. The purpose of further research on the subject should be to obtain methods for calculating these coefficients from other properties of the system, without necessitating their actual determination.

In conclusion, the writer wishes to express his appreciation for the assistance rendered by Donald F. Othmer.

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Practice and Equipment for Absorption Operations

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Whereas in the preceding article the emphasis was on the theory of absorption and on the calculation of performance factors, the article which follows deals chiefly with types of absorption equipment, their characteristics, applications and operation.—*Editors.*

COMMERCIAL operations involving absorption processes include: recovery of natural gasoline from natural gas, recovery of carbon dioxide from flue gas, removal of hydrogen sulphide from natural gas to give a "sweet" product, recovery of solvents from the air-solvent mixtures produced in the manufacture of such materials as nitrocellulose, cellulose acetate synthetic resins and plastics.

These absorption operations fall into two general classes: (1) Those operations involving purification of either the carrier gas or the solute, in which it is important that a selective solvent be used in order to insure a satisfactory degree of separation between the solute and the carrier gas; (2) those operations involving solvent recovery, in which it is important that the solute be readily soluble in the solvent in order to insure maximum recovery. Where the solvent recovery involves a mixture of solvents, all constituents to be recovered should be soluble in the solvent.

A diagrammatic flow sheet showing typical absorption processes using water as a scrubbing medium is given in Fig. 1. It should be noted that the absorption cycle is only a part of the complete installation, since it is usually necessary to recover the pure solute or purify the solvent for re-use. Since the optimum operating conditions are obviously those which give the lowest over-all cost, the absorption and distillation cycles must be designed simultaneously.

There are two factors which must be considered in the design of all absorption units: (1) The driving force (i.e. the tendency for the solute to dissolve in the solution) must be made as large as possible in order to improve efficiency and reduce equipment costs, and (2) the gas and liquid phases must be brought into intimate contact to insure rapid transfer of the solute from the gas phase to the liquid phase. The magnitude of the driving force is determined by process design (choice of solute concentration in inlet gas, operating temperature, operating pressure, outlet liquor concentration and choice of solvent) whereas the intimacy of contact is determined by equipment design.

Process Design[10,12]—For efficiency in absorption, the solute concentration in the inlet gas should be maintained as high as conditions in the preceding operation will permit. As a safety precaution, explosive limits for air solute mixtures should be checked to make certain that the concentrations used are outside the explosive limits[1].

In general, the lower the temperature of the solution, the lower the equilibrium partial pressure of the solute from the solution and the larger the driving force. The transfer of solute from gas to liquid phase results in an evolution of heat (heat of solution) which may be sufficient to adversely affect the absorption by raising the solution temperature. In such cases, it is necessary to provide cooling of the liquid during absorption.

When the inlet gas is not saturated with the solvent, a considerable absorption of heat may result from evaporation of the solvent. This heat effect tends to offset the temperature rise due to condensation of the solute.

An extreme sample of the effect of heat of solution on rate of solution is offered by the absorption of concentrated hydrogen chloride vapor in water. In this system the rate of absorption is limited by the rate of removal of heat. Fig. 2 shows a compact unit fabricated of tantalum which has been designed to give a high rate of heat transfer and thus has a very high absorption capacity for concentrated hydrogen chloride[13].

The operating pressure is usually fixed by conditions preceding the absorption cycle. An increase in pressure increases the partial pressure of the solute in the gas phase and thus favors absorption so that where feasible it is advantageous to operate the absorption column under pressure.

The lower the concentration of solute in the outlet liquor, the more favorable the conditions for absorption, and the less favorable the conditions for the distillation cycle. Thus, the optimum outlet liquor concentration is determined by considering both absorption and distillation cycles. A detailed example of the method of calculating the optimum exit liquor concentration for recovery of acetone is given by Spurlock[3]. In this case the optimum value of mV/L was found to be 0.7, where $m=y^*/x$, y^*=mole fraction of solute gas in equilibrium with liquid of composition existing in body of liquid phase, x=mole fraction of solute in body of liquid phase, and V/L=molal ratio of gas flow (inert plus solute gas) to liquid flow.

In general, for absorptions involving recovery of solute by absorption where the solute is quite valuable, say 5 to 10 cents per pound, Colburn[3, 10] states that the optimum value of mV/L usually lies between 0.5 and 0.8. Although the value of mV/L usually varies throughout the column, use of the value of mV/L for the dilute end of the column frequently gives a satisfactory approximation. Colburn also gives a convenient chart from which the number of transfer units required can be readily determined. Inspection of this chart, reproduced in Fig. 3, indicates that for solvent which enters the tower solute-free and a recovery of 98 percent ($y_1/y_2=50$, where y_1 is mol fraction of solute in entering gas and y_2 is mol fraction of solute in gas leaving), the number of transfer units required varies between 6 and 12 for values of mV/L between 0.5 and 0.8.

The solvent should be selected to give a high solubility of the solute and ready separation from the solute in the distillation cycle. Solvents commonly used are water, oils or similar organic compounds, and solvents which react chemically with the solute.

When a solvent is used which reacts chemically with the solute, the partial pressure of the solute from the solution may be practically zero during the absorption cycle. The compound must be sufficiently unstable, however, to allow ready decomposition of the solute-solvent compound during the distillation cycle. For systems of this type, when the value of m approaches zero, mV/L approaches zero. Reference to Fig. 3 shows that for a 98 percent recovery only four transfer units are required as compared with 6 to 12 transfer units for the optimum absorption cycle where the solute must be recovered by distillation.

A diagrammatic flow sheet for the Girdler process for removing acidic gases from inert carrier gas, using an aqueous solution of ethanolamines is given in Fig. 4. In this process the ethanolamines react with the acidic gases to form amine salts. The solution containing the amine salts is transferred to the reactivator where the solution is heated and the salts are decomposed. The concentrated acid gases are released from the top of the tower and the regenerated amine solution is cooled and returned to the ab-

sorption tower. This process has been used commercially to remove hydrogen sulphide from natural and refinery gases, in the production of nitrogen from the combustion products of fuel gas by the removal of carbon dioxide, and in the production of carbon dioxide from stack gases. A modification of the process in which the solvent contains ethylene glycol, in addition to the ethanolamines, is used to remove water vapor as well as hydrogen sulphide from natural gas. For removal of hydrogen sulphide from natural and refinery gases by the Girdler process, the costs are reported to vary between ½ and 2 cents per thousand standard cubic feet, depending upon the concentration of hydrogen sulphide in the inlet gas[4].

Laboratory tests on the use of acid solutions of cuprous chloride for separation of the olefinic from the paraffinic constituents of cracked petroleum refinery gases are reported by Gilliland and Seebold[20]. The separation depends on the selective reactivity of the olefines.

Equipment Design[10,13]—In general, the requirements for satisfactory absorption equipment are the same as for distillation equipment. While the same types of equipment are used for both operations, the pressure drop through the equipment is of considerably more importance in absorption since the inlet gas is usually supplied by a blower. Blower characteristics and power costs usually limit the allowable pressure drop through the absorber to 1 to 3 lb. per sq. in.

The contactors commonly used may be divided into three classes—those in which contact is secured by imparting energy to the gas phase (bubble cap and sieve plate columns), those in which contact is secured by imparting energy to the liquid phase (Bartlett-Hayward washer and spray towers), and those in which both liquid and vapor streams are distributed (packed towers).

Bubble cap and sieve plate columns have the advantage of positive contact between gas and liquid phases, together with reliability in operation. While both types of column can be provided with cooling coils to remove heat of solution, the sieve plate column is more readily adapted to this type of construction. Recent developments in design of plate columns have led to reductions in pressure drop, so that when necessary pressure drops of 1 to 1¼ mm. Hg per plate can be obtained and pressure drops of 2 to 2½ mm. may be considered normal.

Since the vapor velocity through the holes of a sieve plate must be sufficiently high to prevent the liquid from running through the holes, a minimum vapor velocity is required to keep the plates sealed. Thus, a sieve plate cannot be operated below a capacity of about 30 to 40 percent of the design capacity. This should be considered where wide variations in gas throughout are to be expected.

The violent agitation of the liquid in a plate column increases any tendency toward foaming. For liquids which are known to foam, a packed column may be preferable[5].

Discussions of mechanical design of plate columns are given in references 9 and 10. Methods of calculation of column capacity are given in references, 5, 9 and 10.

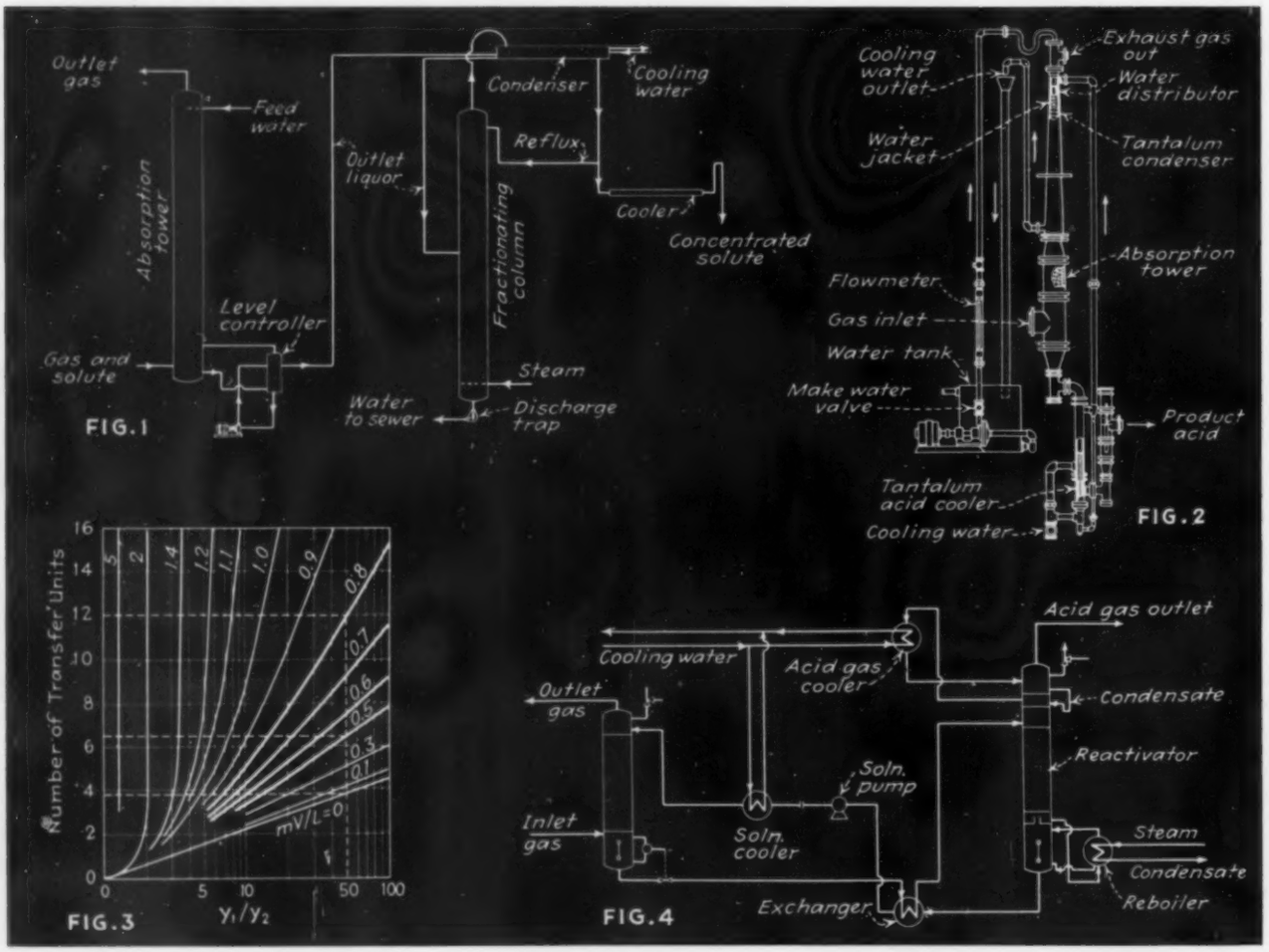
Tests on the operation of a plate type refinery gas absorber with and without intercooler for both winter and

Fig. 1—Typical flow diagram for an absorption system using water as the absorption medium

Fig. 2—Fansteel Type RP absorber for making muriatic acid from concentrated HCl gases

Fig. 3—Number of transfer units as plotted by Colburn (*Trans. Am. Inst. Chem. Engrs.*, 35, 216, 1939)

Fig. 4—Flow diagram of Girbitol process for recovery of acid gases from inert carrier gases



summer conditions are reported by Jackson and Sherwood[14].

Tests on absorption of ammonia and carbon dioxide, desorption of carbon dioxide from water and aqueous glycol solutions, absorption of propylene and isobutylene in three oils, rectification of ethanol and humidification of air in pilot plant and laboratory plate columns, are reported by Walter & Sherwood[18]. Murphree vapor efficiencies ranged from 69 to 92 percent for absorption of ammonia, from 0.65 to 4.2 percent for absorption and desorption of carbon dioxide, and from 4.7 to 24 percent for the absorption of olefines in the three oils. The authors conclude that the major variable in plate efficiency is gas solubility.

In the Bartlett-Hayward scrubber, the liquid is showered through perforations into the rising gas stream by means of a series of cones rotating on a central shaft. This washer has the advantage of low pressure drop. It should be noted, however, that contact is secured by internal moving parts.

Spray towers have the advantage of low pressure drop, but have not been especially efficient due to non-uniform distribution of liquor and vapor. The Vulcan Copper & Supply Co. has recently developed a spray tower in which the flow of liquid and vapor is more nearly counter current[6]. Where necessary, the solvent may be conveniently cooled in conventional heat exchangers between spray sections.

Packed columns have been widely advocated for use as absorption towers because of the relatively low pressure drop and the ease of fabrication. It should be noted that in a packed tower there is no positive means of insuring uniform distribution of liquid and vapor over the entire cross-sectional area of the column. Thus, considerable difficulty may be experienced with channeling of liquid and vapor, with consequent reduction of column efficiency. The opportunity for channeling is increased as the diameter of the column is increased, so that for absorption problems requiring an efficient large column, some other type of contactor may be preferred.

At very low liquor rates (below 0.2 g.p.m. per sq. ft. of tower cross section) the liquor distribution is likely to be unsatisfactory and a plate tower is usually to be preferred. At very high liquor rates (200 g.p.m. per sq.ft. of cross-sectional area, or higher), and low gas rates, high values of H.T.U. are obtained[7]. For such systems consideration should be given to plate or spray type columns.

In the design of packed columns, the following precautions should be observed: (1) In order to insure satisfactory distribution of liquor and vapor, the ratio of tower diameter to packed diameter should be at least 8 to 1. (2) The feed liquor should be initially distributed as uniformly as practical. Uniformly spaced distributing points equivalent to at least $4d^2$ (where d represents column diameter in feet) should be provided. (3) The packing support should not constrict the space for gas and liquor passage.

The surface area of a packing is not necessarily indicative of the relative absorption efficiency of the packing. For normal liquor rates there is insufficient liquor to completely wet any of the common packings. Thus, the wetted surface is usually fixed by the quantity and viscosity of the liquor flowing rather than by the available packing surface. Consequently, a choice of competitive packings of the same size usually depends on factors such as pressure drop or physical properties, rather than on surface area.

Discussions on packed tower and similar types of contactors are given by Deutsch[11] and Johnstone[15]. Data on pressure drop through packed towers, allowable gas and liquor rates, physical characteristics of packings and packing efficiencies are given in references 10 and 12. Allowable gas and liquor rates for tower packings used in refinery gas absorbers are given in 14.

Results of tests on the absorption of acetone in water using a 10-in. tower packed with 1 in. stoneware rings are reported by Othmer and Scheibel[17].

Data on pressure drop, loading and flooding velocities, as well as H.T.U. values for desorption of oxygen from water for drip-point ceramic grid packing, 3x3-in. partition rings, 3x3-in. single spiral rings, 3x3-in. triple spiral rings, 1-in. Berl saddles and 1-in. Raschig rings are reported in reference 21. On the basis of relative pressure drop per transfer unit, the drip-point grid packing was found to give a very favorable pressure drop.

Comparison With Other Methods of Separation—Alternate methods of separation include condensation of solute using either cooling water or refrigeration[16], distillation under pressure, and adsorption. The most practical method of separation for any specific problem can be determined only after a careful consideration of all factors involved.

Condensation of solute has the following advantages: (1) The solute is recovered in a relatively pure condition so that little or no further purification is required, and (2) when the inlet solute concentration is high, the equipment cost and operating expense are likely to be low.

Since the recovery of solute is definitely limited by the partial pressure of solute at the temperature attainable in the condenser, the condensation process is usually limited to a relatively high concentration of solute in the inlet gas. When the carrier gas contains oxygen, it is considered good practice to operate below the lower explosive limit. If the concentration of oxygen in the carrier gas is kept low by the use of inert gases such as nitrogen or carbon dioxide, or by other means, high inlet concentrations of solute may be used safely. In certain operations it may be advantageous to combine condensation with either absorption or adsorption, the major portion of the solute being recovered by condensation and the final traces by absorption or adsorption.

Distillation under pressure is limited to those cases where (a) a reasonable increase in pressure will allow condensation of the carrier and (b) the inlet gas carries a relatively high concentration of solute.

Adsorption has the advantage that the recovery of solute in the boiling range of ordinary solvents is practically complete and is independent of solute concentration in the inlet gas. For solvent recovery it has the further advantage that a mixture of solvents can be recovered, since the adsorption is not selective. The recovery costs for adsorption usually range from 0.2 to 1 cents per pound of recovered solvents and vary only slightly with varying inlet gas concentration, whereas the cost of an absorption system (excluding those systems using a chemical reaction) varies widely with concentration of solute in inlet gas and solubility of the solute in the solvent.[5] As a general rule, adsorption is likely to be more economical for solvent recovery when the solute concentration in the entering gas is below about ½ to 2 percent by weight. In some instances it may be necessary to prepare cost estimates covering both processes before a final decision can be made.

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Design and Applications of Liquid-Liquid Extraction

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Although the principles of liquid-liquid extraction are theoretically based on the concept of molecular diffusion through two liquid films, the practical application of this is complex at the present time and little data are available. In this article the author prefers to stress engineering aspects of operations and design.—*Editors.*

LIQUID-LIQUID extraction consists in separating the components of a liquid solution or mixture by treatment with an immiscible solvent which dissolves one or more of the components of the solution in preference to the others. The laws of diffusion and distribution equilibria similar to, although frequently more complex than those underlying absorption and distillation, govern the transfer of components from the original solution to the solvent. Hence, extraction in its fundamental aspects, engineering conduct, and equipment bears many resemblances to these operations. While probably not so generally useful, extraction provides a means for separating, concentrating and recovering valuable components, or the removal of undesirable impurities, from liquid solutions where distillation is uneconomical or actually impossible. In other cases, even though distillation is practicable and economically feasible, it may result in economies in heat consumption and equipment when used as an adjunct to distillation.

Chemical industry has employed liquid-liquid extraction to a limited extent more or less as an art for many years, but its status as an important chemical engineering operation is relatively new. Its theoretical and engineering principles and background have, however, now been well established, and while much of the technical and engineering data desirable for practical design and operation are yet lacking, progress in this direction is being made. Data are still sufficiently scattered and uncorrelated, and design methods are sufficiently varied and complex to prevent detailed review.

PRINCIPLE OF EXTRACTION

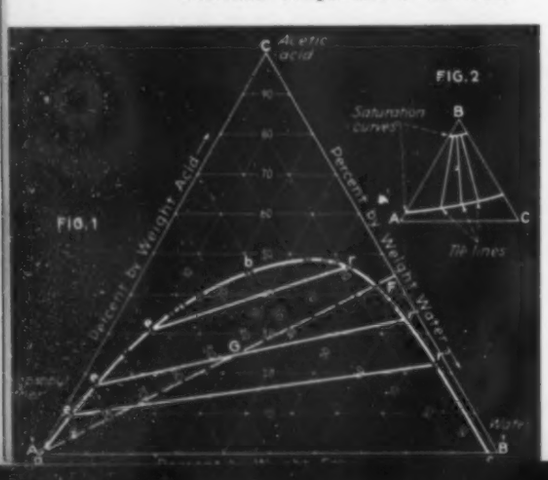
The method is based on the well known fact that many liquids, such as hydrocarbons and water or ethyl or isopropyl ether and water, especially if they are chemically dissimilar, do not dissolve completely in each other, but if mixed, form two distinct liquid layers or phases. A third substance, referred to as the solute, if present initially in the first liquid, will distribute itself between the two layers. With intimate contact and sufficient time, definite equilibrium compositions determined by the chemical nature of the compounds, the concentration, and the temperature, are set up between the two layers. Hence, if a solution of this solute in the diluting liquid is treated with the second liquid (solvent) in proportions which give two layers, the liquids are intimately mixed and allowed to settle, and the solvent then removed from each, a separation and recovery of the solute from the original solution is effected.

As an operation, extraction consists of three parts: (1) contacting and mixing the phases, which can be carried out by a variety of means; (2) phase separation, usually by gravity settling in simple settling tanks, sometimes by centrifuging; and (3) removal and recovery of the solvent from each phase, ordinarily by distillation. The solvent layer is commonly called the extract layer. The other which is undergoing extraction and contains the diluent in larger proportion is called the raffinate.

Two liquids which are almost completely mutually insoluble (entirely immiscible) such as benzene and water, result in two layers on mixing in almost any proportions. The majority of liquids dissolve in each other to an appreciable extent, i.e., are only partially immiscible, such as ethyl ether and water, so that two layers result only if proper proportions of the two are used and one or the other is not present in great excess. This is the situation in most practical applications of extraction. If at all miscible, solvents dissolve to some extent both components of a mixture while some solvent dissolves in the raffinate. At equilibrium all three are distributed between both layers so that the extract in general contains some of both components of the original feed after the solvent is removed, and recovery of solvent from the raffinate is necessary. For example, isopropyl ether extracts both acetic acid and water from a dilute aqueous solution but dissolves more acid than water so that the extract contains dissolved in ether a more highly concentrated acid than the corresponding solution treated. Solvents are said to be selective for that compound which they preferentially dissolve. They differ in degree of selectivity and different solvents may have opposite selectivities for the components of a given mixture. In special cases, only the solute and not the diluent may be dissolved, and substantially none of the solvent in the raffinate layer, so that the extract yields as product the pure solute upon removal of the solvent. The latter need not be recovered from the raffinate. This usually happens where the solution extracted is very dilute. Mu-

Fig. 1—Ternary diagram for the system isopropyl ether-acetic acid-water

Fig. 2—Typical diagram often found when the solvent "B" is partly miscible with both components of the feed



According to the accepted theory supported by the experimental evidence thus far available, the mechanism of transfer of solute from one liquid phase to the other involves its diffusion through two liquid films in viscous flow on adjacent sides of the actual interface, the concentrations at the latter being substantially in equilibrium. If a second liquid film replaces the gas film in absorption, the two-film diffusional mass transfer principles found valid for this operation may be extended directly to the rate of extraction. By analogy with absorption results, much of the diffusional theory of extraction has been developed. Accordingly, the rate of solute transfer from liquid phase W to liquid phase E under steady state conditions at a point in a continuous extraction tower is expressed by equation (1) where dn_A is the number of moles (or lbs.) of solute A transferred in unit time; k_W and k_E are the respective individual liquid film transfer coefficients; $(C_{WL}—C_{Wi})$ and $(C_{Ei}—C_{EL})$ are respective differences between solute concentrations in the main body and at the interface (film driving forces); and A is interfacial contact area. C_{Wi} is related to C_{Ei} by the existing equilibrium. As is customary in similar cases, to deal with situations such as the packed tower where A is not directly measurable, k_dA is replaced by k_adV or k_aSdZ where a is specific contact area per unit volume of tower; V is effective tower volume; S the tower cross section; and Z the tower height. The capacity coefficient k_Wa having the usual units lb. moles/(hr.) (cu. ft.) (unit ΔC) is then employed instead of the specific coefficients k_W and k_E.

Little is known about the respective importance or relative resistances of the two films in extraction, and few values of individual film coefficients have been measured. By analogy with absorption, application of the theoretical diffusional equations indicates that k_W and k_E should be

tual solubility of solvent and diluent is usually increased by the presence of the solute, high concentrations of the latter often leading to complete miscibility.

Rate of solute transfer from diluent to solvent layer is directly proportional to the area of contact and to the degree of agitation. If mixing and time of contact are insufficient for the definite equilibrium compositions to be established between the layers, then actual compositions are governed by diffusion rates and intimacy of contact and approach these more or less closely depending on how the extraction is conducted. For design purposes, extraction rates can be treated theoretically according to the principles of diffusion through two liquid films in viscous flow by methods almost identical with those developed for the related absorption and distillation operations.

TYPES OF APPLICATION

Extraction has widest application in the separation of compounds differing in chemical type and which are difficult or actually impossible to separate by distillation, either because they have identical or almost the same volatilities from the mixture, or are very difficult to vaporize or to distill without decomposition. This is the case with the aromatic-naphthenic and the paraffinic components of lubricating oil in the separation and refining of which various solvent extraction processes are now widely employed. By extraction, high viscosity-index paraffinic oils comparable to those obtained from good Pennsylvania stocks are produced from various Mid-continent and Coastal crudes. Various solvents are now in use, including nitrobenzene, furfural, phenol, crotonaldehyde, liquid propane, β-β'-dichlorodiethyl ether, ("chlorex"), cresylic acid, and a mixture of SO_2 and benzene. The majority of extraction processes in themselves are, however, quite similar. These have been described in some detail by Dunstan,[1] Sherwood[2] and others. The separation of isomers and constant boiling mixtures is a similar possibility.

An analogous application having a similar basis and now undergoing development is the extraction of vegetable oils such as soya bean and linseed to effect their separation into a drying fraction composed of unsaturated glycerides and a non-drying fraction consisting principally of the saturated glycerides.[3] Of the possible solvents for this purpose, furfural and nitroethane, which selectively dissolve appreciable quantities of oil and preferentially the unsaturated glycerides, are apparently the best.

Extraction with such solvents as ethyl ether, isopropyl ether, or ethyl acetate has been used for a number of years to recover a concentrated acetic acid from dilute aqueous solutions and wood distillation liquors. Although recovery of acetic acid from water by distillation is theoretically possible, the relative volatilities of the two compounds differ so little from their mixture that the large steam consumption and equipment required for concentration by distillation and rectification makes this method uneconomical and impractical. By extraction with isopropyl ether, for example, acetic acid is dissolved selectively into the ether layer in relatively concentrated form. The removal of the solvent, together with some of the water in the distillation of the extract, yields a more highly concentrated acid and the solvent for re-use.

Other types of application are possible. Solvent extraction can offer advantages and economies as a preliminary to distillation or vaporization even where these are feasible and easily performed. For example, where a valuable component is present in dilute solution in a liquid of higher volatility, its preliminary concentration by extraction into a solvent and subsequent recovery by distillation from this solvent can be less costly in heat and equipment than the direct distillation of the original solution. It is also often possible to find an extracting solvent differing greatly in volatility from either the original diluent or the compound which is desired to recover so that distillation is made easier. Even where the compound to be recovered is the more volatile component of the original solution, a preliminary extraction may offer economies. Since organic liquids ordinarily have considerably lower heats of vaporization than does water, this type of application is well worth considering especially when the desired compound is present in dilute aqueous solution.

Othmer and Trueger[4] have recently described such a case in the recovery of acetone from dilute aqueous solutions by extraction with such solvents as monochloro-benzene and methyl isobutyl ketone and of ethyl alcohol by amyl alcohol and di-n-propyl ketone. Although either is readily recovered from dilute aqueous solutions in substantially pure form by simple rectification, these authors conclude that a preliminary extraction leads to a lower heat consumption and lower cost of distillation equipment for their separation from the solvent than from the original dilute solution. Dilute aqueous solutions of other volatile organic materials such as methyl alcohol, propyl alcohols, and acetaldehyde may be concentrated by extraction with similar advantages. Extraction in these cases results in a substantial saving in operating cost, principally where the original concentration of the solution is low.

Extraction may be the more feasible method for separating heat sensitive materials since it usually can be carried out at room temperature and with a solvent readily removed at relatively low temperatures. It finds particular application in the removal of small amounts of impurities and coloring matter from solutions. Even if removal by distillation is practicable, extraction is frequently less costly. A solvent selectively extracting the impurity and completely immiscible with the other components is preferable. The removal of coloring substances from concentrated synthetic glycerine derived through the chlorination of propylene mentioned in Table I is one of many examples. Small amounts of valuable products present in a diluent of lower volatility can sometimes be profitably recovered by extracting with a solvent which is less volatile. Where a valuable product is obtained in small concentration and is greatly contaminated in the solution with liquid or solid

(1) $dn_A = k_w(C_{WL} - C_{wL})\,dA = k_E(C_{EL} - C_{EL})\,dA$

(2) $K_w a = \dfrac{dn_A}{(C_w - C_w^*)(S)(dZ)}$

(3) $\dfrac{1}{K_w a} = \dfrac{1}{k_w a} + \dfrac{m}{k_E a}$

(4) $N_{ow} = \int_{y_2}^{y_1} \dfrac{(1-y)_f\,dy}{(1-y)(y-y^*)}$

(5) $Z = (N_{ow})(H.T.U._{ow})$

(6) $Z = n_A/(k_w a)(S)(y-y^*)_m$

determined by the diffusion coefficient of solute in the solvent, the turbulence conditions which govern the effective film thickness, and the mean concentration of the solvent across the film. The specific contact area a is not usually constant for a given type of extraction apparatus but varies widely with operating conditions and physical properties of the two phases. In many cases its variation with conditions is more important than that of the film coefficient in determining the capacity coefficient kwa. Where extraction takes place from or into drops of one liquid suspended in the other, it is probable that diffusion in the bulk of the drop may be an important factor. This can be handled by equation (1) by considering the corresponding transfer coefficient in terms of an equivalent film thickness, as is commonly done in absorption and heat transfer.

For practical purposes, it is usually necessary to define and work with an over-

(7) $(H.T.U.)_{ow} = L_w/K_w a(1-y)_f$

(8) $N_{ow} = \int_{y_2}^{y_1} \dfrac{dy}{y-y^*}$

(9) $N_{ow} = \dfrac{2.3}{(1-mL_w/L_E)}\,\text{Log}\left[\left(1-\dfrac{mL_w}{L_E}\right)\left(\dfrac{y_1-mx_2}{y_2-mx_2}\right)+\dfrac{mL_w}{L_E}\right]$

(10) $(H.T.U.)_{ow} = (H.T.U)_w + (H.T.U)_E(mL_w/L_E)$

(11) $(H.T.U)_w = \dfrac{L_w}{k_w a};\ (H.T.U)_E = \dfrac{L_E}{k_E a}$

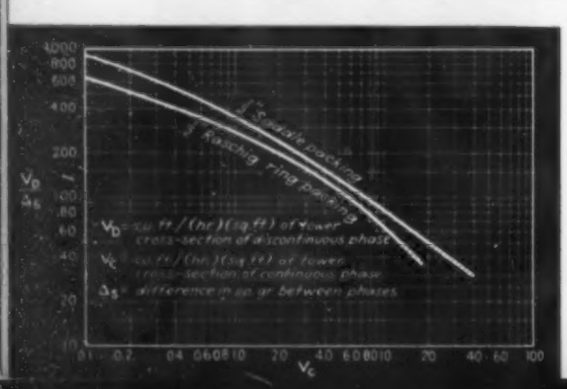
(12) $Z = n_A/(K_w a)(S)(\Delta C_w)_{l.m.}$

impurities, extraction has potential application. Fermentation liquors are an example. Direct vaporization in such cases is frequently complicated by heat transfer problems. The separation of organic solutes from inorganic solids dissolved in the same liquid, usually water, is another field of application, since inorganic compounds are not readily extracted by organic solvents.

A number of specific present and suggested uses of liquid-liquid extraction listed in Table I illustrate various cases in point. The refining of crude rosin is an interesting example of purification by extraction and illustrates a type of liquid-liquid extraction sometimes referred to as fractional distribution. The rosin is dissolved in gasoline or naphtha and the impurities extracted by treatment of this solution by the partially miscible solvent furfural. The Duo-Sol lubricating oil refining process also operates commercially on a similar principle. The components of the feed oil are fractionally distributed between two partially miscible solvents, usually liquid propane and a mixture consisting principally of cresylic acid. Propane selectively dissolves the paraffinic oil, cresylic acid the aromatic-naphthenic components. Countercurrent operation with about nine extraction stages is used, the propane entering at one end and the cresylic acid at the other, the feed oil being introduced in the middle. Cornish[5] purifies vitamins by fractional distribution between immiscible solvents. Hixson and Hixson[6] state that oleic and abietic acids, the principal constituents of "tall" oil obtained as a by-product in the manufacture of Kraft paper pulp, can be separated and recovered commercially by extraction with liquid propane and it is understood that this process is undergoing development. Many other less known and unpublicized liquid-liquid extraction operations are used industrially, especially for the recovery and separation of organic compounds from water.

In some cases, as in the refining of naphthas to remove sulphur compounds where extraction with aqueous caustic soda removes mercaptans as sodium mercaptides, physical solution in the liquid solvent is accompanied by chemical reaction with a solute in the latter.

Fig. 3—Colburn plot of flooding data in liquid-liquid extraction towers. Curves should be used only for rough estimates of magnitudes of flooding velocities



Location of workable solvents and choice of the best is facilitated by phase data for various chemical types with the components of the mixture to be extracted. Such data show the composition range in which two layers or phases exist and the equilibrium compositions of these layers for varying concentrations in the system. They are also the basis for a choice of operating methods and conditions and design of process equipment. Types of phase behavior are qualitatively known to be varied (see texts on physical chemistry and the phase rule, e.g. Bowden[7]). Only in exceptional cases (immiscible solvents and low solute content) is the simple distribution law which states that the solute concentration in the solvent phase is a linear function of its concentration in the diluent phase, even a poor approximation of the equilibrium involved.

Few quantitative data for solvents and systems likely to be of industrial importance are available and their experimental determination for the proposed extraction is usually necessary. Most of the data available may be located through or found in the references given in Table II; the first three list with source the majority of systems measured. Several generalizations given in references (2) and (6) may be helpful in reducing the experimental measurements required but the extent of their applicability is still uncertain.

Phase data for ternary systems are most conveniently and completely defined graphically on triangular diagrams. This is common practice. Other methods of plotting[8] are used to show special characteristics and for design purposes. Plotting the equilibrium concentrations of the component to be extracted in the two phases against each other, both on a solvent-containing and on a solvent-free basis, facilitates comparison of the properties of different solvents.

The ternary diagram, Fig. 1, for the isopropyl ether-acetic acid-water system, typifies the majority of those thus far studied and the class largely found in industrial extraction operations. Here, two of the binary pairs, ether-acid and water-acid which are represented along the sides, are miscible in all proportions. The third pair, ether-water, is only partially so. Points on the saturation curve *abc* between *a* and *b* represent an ether layer just saturated with acid and water; between *b* and *c* a water layer just saturated with ether and acid. Outside the curve only one phase exists, and extractions involving these compositions would be impossible. For all compositions under the curve two phases exist. Lines *er*, *e'r'*, etc., of which an infinite number can be drawn, are referred to as "tie-lines", and connect the compositions of the layers which are in equilibrium with each other (conjugate layers).

Properties of the triangular diagram are such that the composition of a new mixture formed by mixing solutions of two other compositions lies on the straight line connecting the latter and dividing it into segments which are proportional to the weights of the two solutions mixed together. Thus, the ratio GF/GA represents the weight ratio of ether added to a solution of acetic acid and water, F, which gives the composition G. This mixture separates into a solvent or extract layer and a raffinate layer whose compositions are respectively e' and r'. Their amounts are determined by the ratio of the line segments Gr'/Ge'. Fig. 2 typifies the diagram often found where the solvent B is partly miscible with both components of the feed. In this

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all coefficient in terms of an overall concentration difference. This may be written on the basis of either phase, but it is ordinarily best to employ the phase in which the solute is least soluble. For phase W the overall coefficient is defined by (2), where Cw^* is the phase W concentration corresponding to equilibrium with the observed concentration Cs in phase E. This coefficient is related to the individual film coefficients by (3), where $m = \Delta Cw/\Delta Cs$, the slope of the equilibrium curve, and the respective terms represent the overall resistance and the resistances of the films to mass transfer. Unless m is constant (usually only for dilute solutions and nearly immiscible liquids), K_{we} varies with concentration. In this case theoretically its use is justifiable only as an empirical approximation unless variation with concentration is taken into account in integrating equation (2) over the tower.

As shown by Colburn, instead of using transfer coefficients, the fundamental diffusion equation may be arranged to express the rate of extraction and the height of a continuous tower in terms of "transfer units". The expression which results in terms of mole fraction of solute y in the diluent phase W is defined to be the "number of overall transfer units" to which the tower is equivalent. *Now*, or equation (4) where y is the mole fraction of solute in phase W; y^* the value in phase W corresponding to equilibrium with the solute mole fraction X in the solvent phase E; $(1\text{-}y)_f$ is the log mean value of $(1\text{-}y)$ and $(1\text{-}y^*)$; and the subscripts refer to terminal values. The height of the tower is then expressed by (5) where $(H.\ T.\ U.)_{ow}$ is the height equivalent to a phase W overall transfer unit. In terms of N_A, the rate of transfer of solute, and the overall transfer coefficient (6) where $(y-y^*)_m$ is the proper integrated mean driving force. $(H.\ T.\ U.)_{ow}$ is related to $K_{we}a$ by (7), where L_w is the rate of flow of phase W expressed in consistent units. Similar equations may be written on the basis of phase E or either film, using film transfer units and individual film $H.\ T.\ U.$

For dilute solutions and where $(1\text{-}y)_f$ is approximately unity, equation (4) reduces to (8). If m $(= \Delta y/\Delta x)$ is constant, i. e., the simple distribution law holds, and if the two liquids are nearly immiscible so that Lw/Ls is approximately constant, integration gives for the number of transfer units equation (9), where Ls is the rate of flow of phase E, and X_2 is the mole fraction of solute which it initially contains. In this case the overall $H.\ T.\ U.$ is related to the individual film $H.\ T.\ U.$ by equations (10) and (11). $(H.\ T.\ U.)_{ow}$ may then be considered constant through the tower. Under similar conditions equation (2) can be written over the tower as (12), where $(\Delta Cw)_{l.m.}$ is the log mean concentration difference for the two ends. Under other conditions frequently met in extraction, integration becomes complicated and is usually best accomplished graphically or by approximations methods indicated in chemical engineering texts and in the papers by Colburn referred to in this article.

case efficient extraction by suitable methods could theoretically lead to complete separation of the two components into extract of pure *A* and raffinate of pure *C*. In the other case, it is obvious that while acetic acid can be completely extracted from water, the extract must always contain some water.

Methods of plotting tie-line composition data have been given by Bachman[9] and by Othmer and Tobias (ref. 6, Table II) which result in straight lines for many systems tested and facilitate interpolation and reduce the amount of experimental tie-line data necessary. The latter authors plot $\frac{1-a}{a}$ versus $\frac{1-b}{b}$ on log-log coordinates, where a is fraction of solvent in solvent phase and b is fraction of diluent in the conjugate phase. This method has wider application.

Equilibrium involving solvents with complex mixtures having many individually unidentifiable components (such as hydrocarbon oils) can be represented for practical extraction predictions on a triangular diagram by using an additive physical property indicative of the desired properties of extract and raffinate, e.g. by the viscosity-gravity constant.[10] The method is described and data for many solvents and hydrocarbon oil systems given (ref. 4, Table II). Ruthruff and Wilcock (ref. 8, Table II) represent the extraction of soya bean oil with furfural in this way, using the iodine number.

Desirable Solvent Properties—In addition to the obvious desirability of chemical inertness, non-corrosivity to common construction materials, ready commercial availability at low cost, and low toxicity, certain other characteristics in the solvent are an advantage and increase the probability of successful extraction. Excellence in all respects does not preclude, however, successful practice as extraction always rests on an economic basis relative to other possible methods.

High selectivity for that component which it is desired to remove in the extract is desirable. This determines the ease of separation, the number of contacts necessary, e.g. the size of equipment, and the concentration of the desired component relative to the undesired in the extract. It is also preferable, though not necessary, that the distribution of the solute favor the solvent phase, and that the solubility of the solvent in the raffinate be low and change little with increasing concentration of the solute. Recovery of the solvent is almost always necessary and requires, eventually at some point, the expenditure of heat, usually in distillation. Ease and cost of recovering the solvent from both extract and raffinate may be equally or more important than its extraction properties in determining its practical use.

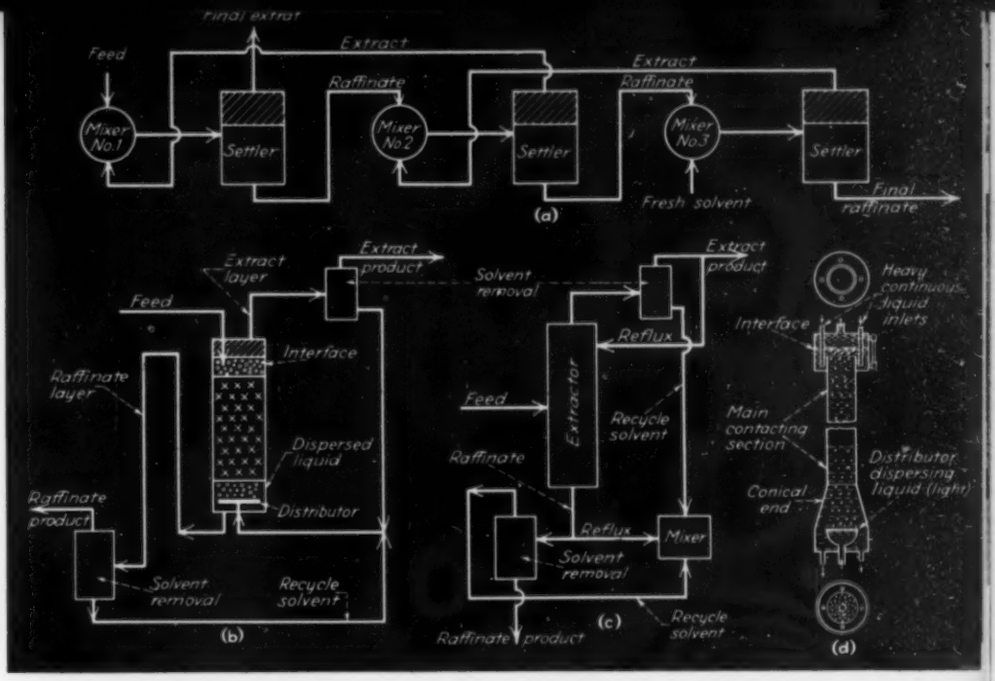

Fig. 4—(a) Three-stage countercurrent multiple-contact extraction; (b) countercurrent continuous tower extraction; (c) countercurrent extraction with extract and raffinate reflux; (d) tower with conical entrance section designed so that velocity of the continuous liquid at entrance and at exit is less than in the main tower contacting section

Finally, a large difference in density between solvent and raffinate is desirable. These are usually separated from each other by gravity settling, or if necessary, centrifuging can be employed. Either is most easily accomplished if density differences are such as to give rapid settling. The latter also is determined by the size of the droplets of the phase dispersed and by the viscosity of the liquid in which settling is occurring as well as by density. In mixing, too small a degree of subdivision, although desirable from the viewpoint of rapidity of extraction, may give difficulty in separation of the two phases. Emulsifying agents can also make phase separation in the settling operation difficult.

SOLVENT REMOVAL

Although distillation is usually the most desirable and practical method for separating and recovering the solvent, other methods are possible. Heating or cooling may reduce the mutual solubility to such an extent that sufficient separation of the solvent from the extract or the raffinate will result. The addition of a third component, i.e., salting out, is also a possibility which sometimes has advantages. A further method having possibilities and advantages which are not fully realized, is to use a secondary solvent to extract the primary solvent from the raffinate and from the extract, finally separating the primary and secondary solvents for re-use by distillation. This can be the case where one has a primary solvent excellent for the extraction but difficult to separate by direct distillation of extract and raffinate. Particularly with aqueous systems there is much more latitude in selecting a secondary solvent with all the necessary properties, than a primary extracting solvent. For example, most organic liquids are at least appreciably soluble in one another, while many are immiscible with water. The author has found this method to be especially advantageous in recovering small quantities of less volatile solvent from the raffinate, and it may avoid the necessity for heating the extract if this be heat sensitive.

OPERATING METHODS

A single contact of feed and solvent is inefficient in use of the solvent, gives poor separation of solute, and a dilute extract. Successive extraction in several steps with portions of the fresh solvent (simple multiple contact) is an improvement and gives any desired degree of stripping of the raffinate if sufficient solvent and number of stages be used but suffices for large scale work only under special circumstances. Hence this method is seldom used in industrial operation.

The more efficient continuous counter-current methods of operation are used almost exclusively for industrial extraction. These are accomplished either according to counter-current multiple contact by using a series of separate mixers each with its individual settling tank or in some type of continuous tower such as a packed or spray tower. Many earlier installations were of the former type. In these, various types of mixers are employed (Table III); baffled or orifice columns, mechanical agitators, and jet mixers being common. Especially the latter two give such good contact that equilibrium between the phases is attained, but equipment and power costs are considerable. Very little engineering data for the performance efficiency of such contactors and extraction systems have, however, been made available. The nitrobenzene process for extracting lubricating oil, for example, uses

this method and employs a 5-stage extractor. Each stage consists of a tank 3½x3½ ft. equipped with a turbo-agitator for mixing and a 13x5 ft. settling tank. Some 50,000 gal. of oil per day is treated with 75,000 gal. of solvent.

Increasing the number of stages reduces the quantity of solvent required for a given degree of extraction and vice versa. Two to five stages are common, more than seven to ten rarely being economical. There is a theoretical minimum ratio of solvent to feed for any given separation corresponding to an infinite number of contact stages. It is usually desirable to employ solvent ratios 50-100 percent greater than this minimum.

Use of Reflux—As in distillation, reflux can be used under certain conditions in either multi-stage or continuous tower extraction to improve the degree or cleanness of separation, the concentration of the extract, or to reduce the number of stages. It is less widely applicable than in distillation, is subject to certain restrictions, and is sometimes of no value. Refluxing the extract is accomplished by introducing the feed at a central position in the extraction unit and returning a portion of the extract layer after removal of the solvent (usually just to saturation) to the extract section. Where it can be used, this provides a greater separation of the two components of the feed in the extract than would otherwise be possible. Theoretically, separation can thus be made complete if the solvent is partially miscible with both feed components. Raffinate reflux is supplied by mixing and returning with the entering solvent a portion of the raffinate. This increases the degree of stripping, or conversely reduces the required number of theoretical stages. Reflux is usable only in such amount and in those situations where two layers still result and where its density differs from that of the extract or raffinate. The improvement in results is obtained by the use of larger quantities of solvent, or what is equivalent, a larger heat consumption.

Table I—Some Present or Suggested Industrial Applications of Liquid-Liquid Extraction

Material Treated	Object	Typical or Suggested Solvents	Separation	
			Extract	Raffinate
Mixture of hydrocarbons in lube oil range	Improved lube oil	Nitrobenzene propane-cresylic acid; phenol; furfural; BB' dichlorethyl ether	Naphthenic-aromatic and paraffinic fractions, either of which may be the extract	
Petroleum naphthas	Removal of sulphur, esp R-SH	Caustic soda and added organic solvents; liquid SO_2	Caustic plus sulphur	Naphtha
Dilute aqueous acetic acid	Recovery of conc. acid	Ethyl acetate; isopropyl ether	Conc. acid	Water
Aqueous 70% ethylene diamine	Anhydrous ethylene diamine	Aqueous NaOH	Ethylene diamine	Aqueous caustic
Tall oil-mixture of rosin and fatty acids	Separation and recovery of the acids	Propane; nitroethane	Either oleic or abietic acid may be the extract, dependent upon solvent	
Impure aqueous lactic acid	Purification concentration of acid	Isopropyl ether	Conc. acid	Impure water solution
Crude rosin	Decolorizing and purifying rosin	Distribution between gasoline and furfural	Furfural, sol'n of resins, color, etc.	Gasoline solution of rosin
Colored, impure conc. aqueous glycerine	Decolorizing, purifying	Xylene	Impurities	Glycerine
Dilute aqueous acetone	Recovery concentration	Chlorinated hydrocarbons (e.g., monochlorbenzene); furfural; methyl isobutyl ketone	Conc. acetone	Water
Dilute aqueous ethanol	Recovery concentration	Amyl alcohols; d-n-propyl ketone	Conc. ethanol	Water
Vegetable oils, e.g., soyabean	Production of drying oils	Furfural; nitroethane	Unsaturated triglycerides (drying)	More saturated oil
Impure aqueous glycerine	Recovery, conc., purification of glycerine	Certain alcohols, amines, ketones, and others	Either glycerine or aqueous solution may be the extract	
Dilute aqueous furfural	Concentration	Ethyl acetate; aromatic hydrocarbons	Conc. furfural	Water
Coal carbonization liquors	Extraction of phenol	Alkali solution and others		
Naphtha range hydrocarbons	Separation of cyclics and paraffinics	Aniline and certain other amines; 97% or better acetic acid		
Petroleum naphthas	Separation of high and low octane fractions	Liquid SO_2	Aromatics or unsaturates	Naphthenics and paraffinics

Continuous Towers—Various types of counter-current continuous towers (Table III) are possible and are coming into wider use because of better understanding of their principles, cheapness, and improvement in their construction and operation. Their performance is governed by the rate of interphase diffusion and in turn to a large extent by the contact area obtained. Towers such as the packed and the spray which give truly continuous contact have the advantage of higher theoretical efficiency, but this is often not realized because of poor contact between the phases. The lighter liquid enters the bottom of the tower and leaves at the top. The heavy liquid flows in the opposite direction. One liquid is broken up into droplets by a suitable device and flows through the other continuous phase because of a difference in density so that contact and settling are occurring simultaneously. The operation of the packed and unfilled spray towers is analogous. In the former, dependence is placed on the packing to produce sufficient contact area between the liquids; in the latter one liquid is subdivided by a suitable distributor plate into small droplets which pass through the column with little or no recombination under proper conditions of design and operation. Either liquid may be broken up, but if that flowing in larger quantity is made discontinuous, better extraction efficiency is frequently obtained.

In the packed and spray types, settling sections or chambers are provided at each end. The interface between light and heavy liquid is usually maintained at a level in the top settling chamber by a suitable control device when the lighter liquid is discontinuous and in the bottom chamber when the heavy liquid is discontinuous. Having the heavy liquid leaving the bottom of the tower pass through an inverted U loop adjustable in height is a common, flexible, and convenient method of controlling the interface level. For lubricating oil extraction it is common practice to maintain the interface level at an intermediate position in the tower so that the top section operates with the heavy liquid discontinuous. In the lower, the lighter liquid is discontinuous. Packing in this case is also arranged in discrete sections with an unfilled space between. This apparently avoids flooding with these heavy viscous liquids.

Relatively few quantitative data generally applicable to the design of large scale columns have been published. Most of those available can be found in Perry[8], Row, Koffolt, and Withrow[11], Comings and Briggs[12], and Colburn and Welsh[13], who summarize most of the earlier work. Row, Koffolt, and Withrow give design details and performance data for various types of towers nine inches in diameter. They recommend Raschig ring or Berl saddle packings over sieve plate or "bubble cap" plate towers, but this conclusion may not hold generally because of the particular design and operating conditions employed in relation to the high surface tension between the liquids used. However, experimental work and practical operating results have confirmed the conclusion that ordinary "bubble cap" towers are very inefficient liquid-liquid contactors. They have been rarely used for extraction but a greatly modified version is known to be successfully employed in at least one industrial operation.

Sieve plate towers have had successful industrial use and are reported to be effective contactors. In these, perforated plates are set at intervals. The heavy liquid flows downward from plate to plate through overflow pipes adjusted to maintain an interface level at the desired height on each plate. The lighter liquid passing upward is broken up by the perforations in the plates, recombines at the interface, and then proceeds to the next plate. Plate efficiency is governed by the height of continuous liquid on the plate and by the size of drops formed.

A type of baffled plate tower recently introduced is receiving increasing attention for industrial extraction. Solid baffle plates filling only partially the column cross section and provided with a short lip to form a tray are suitably spaced and staggered on opposite walls of the tower. The light liquid flows up underneath, around the trays, and up through the free area to the tray above. The heavier liquid flows down to the tray at the edge near the wall, across the tray, and overflows the lip to the tray below. This tower is a version of the wetted-wall type and depends upon length of travel rather than subdivision to provide sufficient contact area. Various types of internally agitated towers with mechanical stirrers have had some extraction use, but do not appear to have enjoyed wide favor because of expensive construction and power costs.

Flooding—Maximum throughput for continuous towers is limited by a flooding point above which the discontinuous liquid commences to be ejected back out of the tower along with the continuous liquid. This results in unsatisfactory operation. The larger the flow of one phase, the smaller is that permissible to the other before flooding is reached. In general, the greater the difference in densities between the liquids and the larger the drop size in the spray tower or the packing size in the filled portion (flooding velocity varies with the type of packing, saddles for example, permitting higher throughputs than the same size rings), the higher is the possible throughput. Generally, allowable liquid throughputs are considerably larger for spray than for packed towers, the former having two to six times larger allowable flow rates depending upon particular conditions and tower design. In a recent study, Blanding and Elgin[14] have described in detail the flooding characteristics of spray and packed towers and report data for two liquid pairs with different drop sizes and type of 0.5 in. fillings. They show that entrance construction has a great influence on flooding. If this is designed so that the velocity of the continuous liquid at its entrance, and especially at its exit where the discontinuous liquid enters, is less than in the main tower contacting section, higher throughputs are possible. This can be arranged by using a conical entrance section, Fig. 4(d). The plot of Fig. 3 prepared by Colburn, which represents very roughly the available data, gives an indication of permissible flows with 0.5 in. packings.

Plant Towers—Packed and spray towers up to 80 feet high are employed in the extraction of acetic acid from water with solvents such as isopropyl ether and ethyl acetate. In refining kerosenes with liquid sulphur dioxide, ring-packed towers 30 feet high and three feet in diameter are used. A 12-foot high experimental tower packed with one inch rings has been found to be equivalent to three to six theoretical stages in extracting lubricating oil with furfural at 200 to 220 deg. F. and to handle from 400 to 1,700 gal. of oil/(hr) (sq.ft.) of tower cross section. Plant towers for this process are seven feet in diameter and packed with 1½ inch rings. Packed towers four feet in diameter and 60 feet high with packing arranged in four foot sections with two feet of free space between (to prevent flooding) are in use for treating 250 bbls. of gasoline with 40 bbls. of caustic soda solution per hour. Similar towers 5½ feet in diameter and 60 feet high with the continuous packed section equal to 50 percent of the height can handle 450 bbls. of gasoline per hour countercurrent to 15 percent by volume of caustic soda solutions.

The Vulcan Copper and Supply Co. has designed and built continuous extraction columns having a total feed capacity for a single unit of 16,000 gal. per hr. with a density difference of 0.187 grams per c.c. Each tower has an extraction efficiency equivalent to at least six transfer units, and is designed with large free openings to avoid difficulty due to clogging.

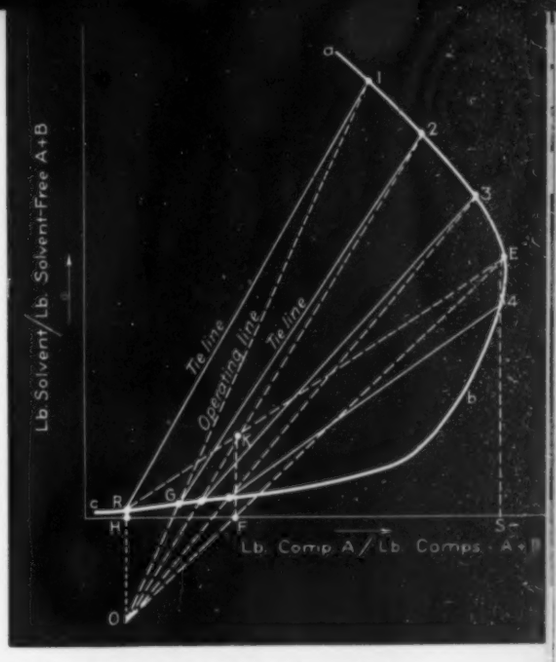

Fig. 5—Maloney and Schubert method for calculating number of theoretical equilibrium contact stages for countercurrent multistage extraction

DESIGN CALCULATIONS

The number of theoretical equilibrium contact stages required for any given set of extraction conditions can be calculated graphically by several recently developed methods.[7] All are based on the same mathematical rela-

Table II—Summary of Sources of Available Phase Equilibrium Data for Extraction

Author	Reference	Nature of Data
1. Smith, J. C.	Ind. Eng. Chem. **34**, 234, 1942	Lists all systems and source references for which complete data are available.
2. Elgin, J. C.	Chemical Engineers' Handbook, McGraw-Hill, N. Y., 2nd Ed., p. 1220, 1230, 1231, 1941.	Lists many systems by source reference.
3. Brancker, A. V., Hunter, T. G., and Nash, J. W.	Ind. Eng. Chem., Anal. Ed. **12**, 35, 1940.	Summarizes and lists many systems.
4. Thompson	Science of Petroleum, Ed. by Dunstan, Vol. **3**, p. 1829, Oxford, N. Y.	Data and diagrams for wide variety of solvents and hydrocarbon oils.
5. Othmer, D. F., White, R. E. and Trueger, E.	Ind. Eng. Chem. **33**, 1240, 1941.	Variety of solvents with acetic acid-water, ethanol-water, and acetone-water.
6. Othmer, D. F. and Tobias, P.	Papers presented before Division of Ind. Eng. Chem., A.C.S., Memphis Meeting, April 20–24, 1942.	Systems: toluene-n-heptane-acetic acid; and acetaldehyde-water with various solvents.
7. Hixson, A. W., and Hixson, A. N.	Trans. Amer. Inst. Chem. Eng. **37**, 927 (1941).	System: liquid propane, abietic acid, oleic acid.
8. Ruthruff, R. F., and Wilcock, D. F.	Trans. Amer. Inst. Chem. Eng **37**, 649, (1941).	System: furfural-soya bean oil.

Table III—Equipment and Methods in Liquid-Liquid Extraction

Contacting Liquids
1. Mixers:
   a. Air agitators
   b. Mechanical, propeller or turbo agitators
   c. Flow or jet mixers
   d. Orifice or baffled columns
   e. Pumps
2. Continuous towers
   a. Spray
   b. Packed
   c. Sieve plate
   d. Modified bubble plate
   e. Baffled columns

Phase Separation
1. Gravity settling
2. Centrifuging

Solvent Removal and Recovery
1. Distillation
2. Heating or cooling
3. Addition of a third component, e.g., salting out
4. Extraction with a secondary solvent followed by distillation to separate primary and secondary solvents.

tions but differ in the diagram employed for their graphical solution. The method of Maloney and Schubert which employs a plot of the phase equilibrium data in terms of lb. solvent/lb. of components *A* and *B* in the extract versus lb. component A/lb. component *A+B* in the raffinate on a solvent-free basis is illustrated for counter-current multistage extraction in Fig. 5. As *abc* is the saturation curve, then the two-phase region is to the left. The feed composition is represented by point *F*. The mixture of feed and solvent which is determined by the ratio of solvent to feed used, is given by point *K*. Points *H* and *R* represent the raffinate to be obtained on a solvent-free and solvent-containing basis, respectively. The composition of the corresponding extract is given by point *E*, which lies on the intersection of line *RK* extended with the saturation curve. An operating point *O* is located at the intersection of the vertical line through *R* and *EF* extended. The extract layer corresponding to stage 1 is in equilibrium with the raffinate and is found by drawing a tie-line through *R* locating point 1. The raffinate of stage 2, point *G*, is located by the intersection of the line *O-1* with the raffinate end of the saturation curve. The extract of stage 2 is found by drawing the tie-line through *G*, locating point 2. Repeating the process until the extract composition *E* is equalled or exceeded fixes the theoretical number of steps or stages, in this case between 3 and 4. The percentage yield of extract is given by distance *FH*/distance *SH*×100. The procedure is similar where reflux is employed, but in this case the procedure is divided into calculation for the extract section and the raffinate section, the corresponding operating points being located from the reflux ratio.

Actual stages, or conversely, equipment performance, can be calculated in terms of the theoretical equilibrium stages and a stage efficiency factor. Similarly, the height of a continuous tower can be estimated if the height equivalent to a theoretical stage (analogously to the H.E.T.P. in distillation) is known or measured experimentally. Continuous towers are also calculated in terms of the number of equilibrium transfer units by the methods of Colburn.[15]

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Theoretical and Industrial Aspects of Crystallization

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The concept of a film surrounding a growing crystal through which the solute must diffuse is not acceptable to this author who, instead, prefers the recently developed Ross hypothesis of multiple hydrate formation. The phenomenon of crystallization and principles of equipment design are treated from this interesting angle.—*Editors.*

IT IS THE BELIEF of this writer that the hypothesis most helpful in understanding crystal formation and growth was set forth by Ross[1] in 1938. A brief plagiarism properly belongs in such an article as this.

Ross suggests that the process of dissolving a substance in water involves definite chemical reaction with the water, resulting in new compounds which can be designated as molten hydrates of the solute. The reaction is attended by the usual energy rearrangements and the new compounds have their own particular physical properties such as melting and freezing points, etc. These are in equilibrium and they will progressively change composition with increasing or decreasing temperatures. It is probable that most salts will tend to hydrate to as great a degree as possible and mix mechanically with any excess water. The greater the hydration is, the lower the melting point will be. These very low melting hydrates could not exist in the solid phase except at extremely low temperatures and it is usually impossible to isolate the solid phase because of the formation of ice before the required temperature lowering can be reached. However, this need not deny their existence in the liquid phase nor militate against this concept of solution. It has been proved experimentally that the true melting points of the solid-phase-stable hydrates are the temperatures of true saturation of a solution having the composition of the hydrate.

With this theory in mind, the formation of a crystal is simply a process of freezing, just as ice is created from water. Upon lowering the temperature of a solution, a molten hydrate freezes to the solid state. The heat effects are considered a combination of the heat of reaction and the heat of fusion, or what is called the "heat of crystallization."

When heat is removed from the molten hydrate, it can be assumed that a few molecules located at the point of heat removal will be prematurely cooled to their solidifying point before the bulk of the solution reaches this temperature, and that nuclei are formed. These nuclei agglomerate and small crystals begin to grow. The small crystals, as shown by photographs in Figs. 1 and 2 apparently possess fields of attractive force surrounding their points, but the intensity of these fields varies at different points on the same crystal. These fields attract other nuclei which attach themselves in an orderly arrange-

ment to the growing crystal, thus determining its specific structure.

Experimental evidence shows that the nuclei have rather weak fields of attractive force, but the small crystals have much stronger fields and grow more rapidly.[1, 2] Each crystalline substance appears to have its own inherent maximum rate of growth under ideal conditions. These maximum rates of growth can be established experimentally under forcing conditions and the data can be used for large scale design. Usually substances of great solubility have high maximum rates of growth. Obviously if more nuclei are made available than can be assimilated by a growing crystal, the excess will start other crystals.

The above is a very brief outline of the Ross hypothesis and many valuable conclusions can be drawn from a detailed consideration of it. It is at variance with the Miers[3] theory which holds that within the "metastable" zone, which lies between the solubility and a "super-solubility" curve, appreciable quantities of new nuclei will not form. Instead, if any solute is thrown out it will deposit only on crystals already present. In the labile, or higher concentration zone, which lies above the "metastable" band, the solute thrown out will either form new nuclei or deposit upon crystals already present, or both. Great difficulty attends reproducible results in the determination of a "supersolubility" curve. With KCl dissolved in an aqueous NaCl solution, the "supersolubility" curve of KCl seems to be non-existent[3] or coincides with the solubility curve.

The Ross hypothesis is also at great variance with any of the theories involving diffusion of the solute through a film surrounding the crystal. The Ross photographs, Figs. 1 and 2, showing the apparent attractive fields of force surrounding the crystal points, rather effectively disprove the film diffusion theories. However, in the old-fashioned unagitated tank type crystallizers, diffusion rates of the solute through the bulk of the solution are undoubtedly a factor in the rate of growth of the crystals thus produced.

It has been stated in the past that the rate of crystal growth is a function of the supersaturation of the bulk of the solution in contact with the crystal. The Ross theory does not admit of this contention.

For the design of crystallizer equipment the Ross theory offers a very practical approach for the production of crystals of a given size. Unfortunately pure solutions are rarely found in industrial practice. For this and other reasons, each solution should be tested experimentally for crystal growth. Many factors will influence this, as shown in Table I.

The qualitative effects of some of these factors can be reasoned, others are obscure in light of present knowledge. It is generally thought that colloidal impurities retard growth or perhaps more correctly stated, give a crop of smaller sized crystals. This may be due to an inoculation effect. The presence of urea as an impurity during crystallization is stated to change NaCl and KCl crystals from their normal cubic system to an elongated shape. The use of the same crystallizer for different crystal products without a thorough cleaning between batches, can greatly affect crystal form. During the crystallization of copperas from an acid solution, the final crystal size is greatly affected by the concentration of loosely held H_2SO_4. One investigator working at high temperatures and pressures with KCl solutions reports large crystal size obtained with extremely rapid cooling. The use of seeds is subject to fairly accurate mathematical treatment, but only if the agitation or contact between the seeds and the supersaturated solution is uniform. There is an optimum degree of agitation for production of a given size crystal crop. Too much agitation will grind the crystals against each other or carry away the agglomerating nuclei, thus resulting in smaller sizes. Adequate instrumentation for control of conditions makes possible reproducible results which would otherwise be impossible.

Table I—Factors Influencing Crystal Growth

(1) Amount and nature of impurities
(2) pH of solution
(3) Temperature and concentration level of crystallization range
(4) Use of seeds, their size and number
(5) Period of retention
(6) Degree of agitation
(7) Rate of cooling
(8) Density of crystal slurry maintained
(9) Constancy of conditions.

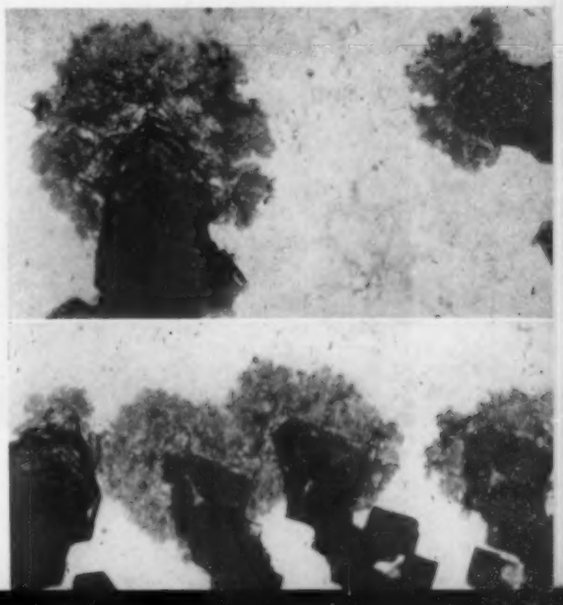
YIELDS AND HEAT EFFECTS

The best opportunity for determining yields is during experimental investigations of crystal growth. Many errors, some of large magnitude, can occur if ordinary stoichiometric methods are used, involving published solubility data. Even though the published data are correct, they give equilibrium values not achieved in the relatively short time of contact in a modern crystallizer, and the supersaturation of the end liquor is not taken into account. Moreover, the data are for pure solutions which are seldom encountered in the chemical plant. For example, manganous sulphate solutions resulting from the leaching of ore contain varying concentrations of dithionates which apparently give considerably higher solubilities than are recorded, and in turn alter the hydrate composition which crystallizes out at a given temperature. A further complication results from the progressive decomposition of the dithionates. In a vacuum crystallizer the heat removal is attended by vaporization of the solvent. Due allowance in yields must be made for this usual loss of solvent and this involves fairly accurate calculation or experimental determination of the heat effects if large errors are to be avoided. This is particularly true if the crystal involved is a hydrate.

Calculation of the heat effects is not involved if the various physical data such as "heat of crystallization," heat of concentration, specific heats of solutions and crystals, are available in the literature. Other heat effects should be recognized, such as radiation to or from the apparatus or heat produced by operation of such mechanical auxiliaries as circulating pumps and agitators. This may be a surprisingly large quantity.

From economic considerations in connection with yield determinations, the cooling range is important as it determines yields and operating costs. Frequently the maximum initial concentration and temperature are established inherently by the process, but the end point may be subject to the designer's control. In general, the lower the level from which heat is removed, the more costly is its removal, but due to the shape and level of the solubility curve an additional yield at a lower temperature may more than offset the larger incremental cost. Each case should be considered on its own merits and generalization is dangerous. However, with vacuum crystallizers, whether batch or continuous, there is a sharp dividing line between low- and high-cost heat removal levels. The low-cost level extends down to the temperature at which the vapor can be condensed with available cooling water. For temperatures below this, steam jet vapor compressors are used and their operation entails high-cost heat removal. With a maximum cooling water temperature of 85 deg. F. and a boiling point rise of 10 deg. F. for the final mother liquor, the lowest practical temperature to which the solution can be cooled without the use of a vapor compressor is 103 deg. F. With a vapor compressor, the lowest practical temperature is approximately 40

Figs. 1 and 2—Ross photographs of the apparent attractive fields surrounding the points of KCl crystals



deg. F. With vacuum crystallizers batch operation always involves the least expenditure of water and steam for the removal of given quantity of heat; but as the quantity of solution to be cooled increases there is a point at which the initial cost of batch crystallizers exceeds that of a continuous crystallizer installation.[4] The usual fixed charges must then be balanced against operation cost.

Modern crystallizer design is usually a compromise between high capacity and large crystal size. Many crystals produced in high capacity apparatus have favorable size for filtering, washing and drying. However, there are important demands for larger sizes. Agricultural $(NH_4)_2SO_4$ used for top dressing of the soil should be of sufficiently large crystal size to prevent wind loss. Photographic hypo of "pea" or "rice" size continues to be in demand, largely due to unwarranted precedent.

Years ago in the prechemical-engineering era, most crystals were produced in unagitated wooden tanks cooled by radiation to the atmosphere. An early improvement consisted of strings or rods hanging down into the tanks. This provided two grades or purities of product. The large crystals attached to the rods were of high purity. Those falling to the bottom of the tank, being collected with the dirt and settled suspended matter of the solution, were impure. This early practice gave rise to the belief which still persists in some quarters that large crystals are the purest. Contrary to this belief, large crystals occlude mother liquor, with whatever impurities it may contain, to a greater extent than do small crystals. Regardless of the purity factor, crystals which are above a certain size and are relatively uniform offer definite economies in further processing. They can be more completely freed from mother liquor on a rotary vacuum filter or centrifuge, and can be finally dried with less expenditure of heat.

In a German patent, No. 630,506 issued to Otto Meyer in 1936, the following comparison is made with KCl:

Size	A Percent	B Percent
Larger than 0.5 mm....	0.4	15.0
Between 0.5 and 0.3 mm.	7.0	40.0
Between 0.3 and 0.1 mm.	82.0	42.0
Smaller than 0.1 mm....	10.6	3.0

In the same centrifuge 9 percent moisture was obtained for sample A, and 4 percent for B. In the same rotary dryer with the same fuel consumption, 150 tons daily capacity was obtained for A and 500 tons for B.

Another valuable property of larger crystals is their greater freedom from "caking" in storage. This is a highly desired goal and will justify on its own account some additional first cost for crystallizer equipment. It is apparent that future efforts in crystallizer design will be directed toward simultaneously producing higher capacity and larger crystal size. To this end, an understanding of the minutiae of crystal formation and growth, as expressed by Ross, is invaluable.

Before leaving the subject of crystal size, it is of timely interest to reflect that certain explosives and pyrotechnics require extremely small crystal size and that better properties exist in the product if the size is produced by true crystallization rather than by subsequent grinding. One satisfactory method employed for this purpose is spraying the solution into a large volume of cold air to produce instantaneous chilling.

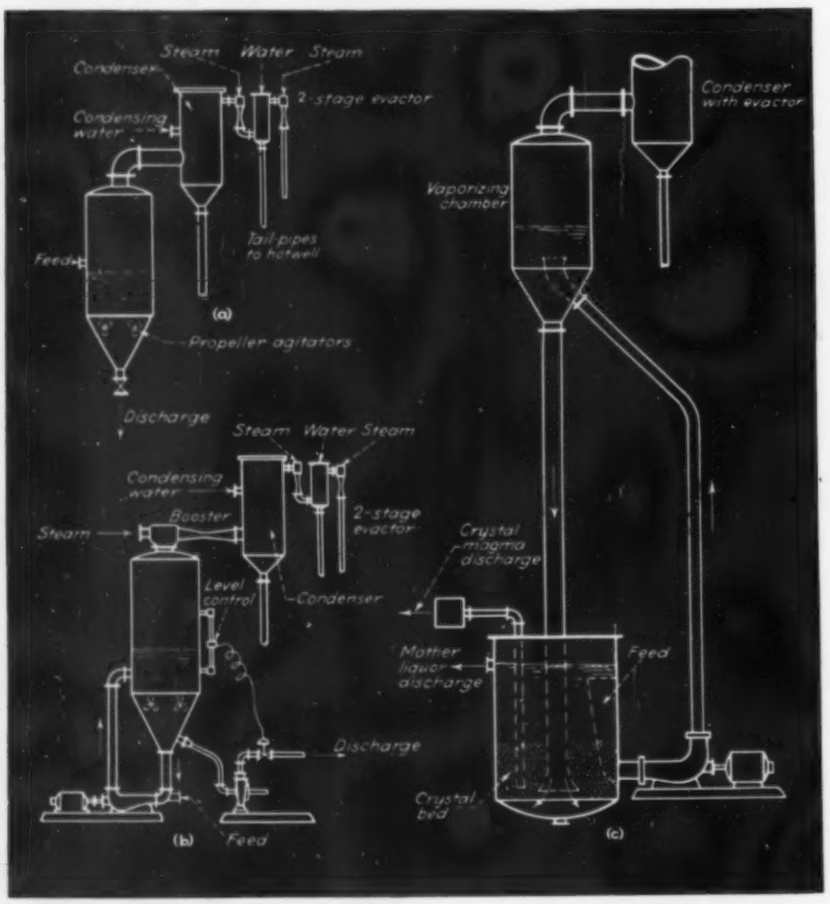
DESIGN OF EQUIPMENT

In the design of commercial crystallizers there are other factors of great importance besides steam and water economy, capacity and crystal size. Probably the next most important consideration is the prevention of crystal growth on the walls and members of the crystallizer itself. The absence of such deposits gives the apparatus a higher percentage of availability, reduces labor for washouts and causes less interference with the continuous operation of the plant.

Any crystallizer design involving heat transfer surfaces must be equipped with scrapers or members passing very close to such surfaces, to prevent crystal build-up. The Swenson-Walker crystallizer is illustrative of this type. In general, its initial cost is higher than that of a vacuum crystallizer. This is especially so when expensive metals are required to combat corrosive solutions. Coil cooled or jacketed tanks are not practical, except in special cases, due to the difficulty of keeping their surfaces clean. Even in the Swenson-Walker crystallizer, the helical-flight rotating members are subject to excessive wear and the cooling jackets become fouled if poor quality cooling water is used. In both cases the result is decreased capacity, but even with these objections there are still some warranted applications for the heat-transfer type of crystallizer. In general, these include the cooling of solutions with boiling point rises which are too high for vacuum crystallizers, or for low temperature ranges in which vacuum crystallizers are not practical. For small-capacity batch operations a Swenson-Walker crystallizer frequently can be purchased at a more advantageous price than a vacuum crystallizer.

Modern crystallizers are predominately of the vacuum cooled type. Where applicable, they are lower in first cost,

Fig. 3.—(a) Batch type vacuum crystallizer; (b) continuous type vacuum crystallizer; (c) Krystal or Oslo continuous type vacuum crystallizer



lower in operating cost, occupy less floor space and can produce favorable crystal size. By definition, a vacuum crystallizer is a cooling device in which a portion of the solvent is vaporized, thereby removing heat from the remaining solution and crystals. The vaporized solvent is condensed and usually is not returned to the crystallizer. From this it is apparent that some evaporation is inherent in a vacuum crystallizer. This evaporation is helpful in increasing yields. In a process which requires both crystallization and evaporation, the byproduct evaporation of the crystallizer is an important economy which is not present in any heat-transfer surface type crystallizer.

This writer prefers to classify as a crystallizer, any device which produces crystals essentially by cooling a solution. A device which produces crystals essentially by evaporation of a solution should be classified as an evaporator, or more specifically, a "salting out" type evaporator. Glauber's salt or other substances having a relatively steep solubility curve which increases with temperature are produced by cooling in a crystallizer. Sodium chloride and anhydrous sodium sulphate which have, respectively, a rather flat solubility curve, and one which decreases with increasing temperature, are produced by evaporation in a "salting-out" type evaporator.

Vacuum crystallizers at present fall into two broad classifications: one in which vaporization takes place from the main bulk of the slurry in which the crystals are more or less uniformly suspended, and the other in which vaporization takes place from solution which is relatively free of suspended crystals. In the latter there is a settling zone containing the main crop of crystals, and the supersaturated solution from which vaporization has taken place is made to circulate through the main crystal bed. The latter is known as the Krystal or Oslo type.[5] Both designs have their advantages. Fig. 3 illustrates the first type for batch and continuous operations as well as the latter type which is used for continuous operation only.

Types shown in Fig. 3 (a) and (b) have propeller agitation to keep the crystals in suspension. This type of agitation has a horizontal rotary component which exerts a radial pressure against the sidewalls of the vessel. This pressure, in addition to the hydrostatic head, is probably responsible for the lack of vaporization at the submerged walls and thus explains the relative absence of crystal growth on them. The batch crystallizer shown in Fig. 3 (a) can be operated indefinitely without lost time for washing. Each succeeding batch, being somewhat above its saturation temperature, dissolves any crystal formation on the walls. The rate of cooling is readily regulated by an absolute pressure controller actuating the flow of water to the condenser. Also, seeding with a known number

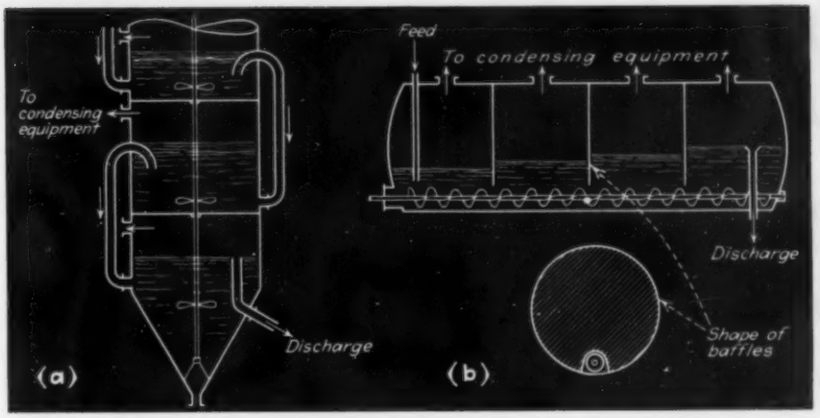


Fig. 4—Two types of the Meyer design of continuous multi-stage vacuum crystallizer

and size of crystals is readily accomplished. Either or both of these operations gives good control over crystal size. Conditions can be adjusted so that each batch provides the required amount of proper size seeds for the next batch. A limitation of this type is the difficulty of maintaining a uniform suspension after the crystals have reached a certain size. This limitation likewise applies to the continuous type as shown in Fig. 3 (b), but it does not apply to the Oslo type illustrated in Fig. 3(c).

The continuous type shown in Fig. 3(b), in addition to the propeller agitation which gives the beneficial radial pressure against the sidewalls, also employs a large recirculation stream into which the hot feed is introduced. This recirculation is sufficient to restrict the temperature of the discharge from the circulating pump to not more than 5 deg. F. above the temperature of the main body of the solution, regardless of the feed temperature. This limits the extent of supersaturation and the range through which flashing occurs, even though the difference between feed and discharge temperatures may be great. By this means, entrainment losses and salting-up of the equipment in general are reduced to a minimum, and favorable conditions are established for forcing crystal growth.

The Krystal type shown in Fig. 3(c) employs the same scheme of recirculation and feeding; but the settled crystals are maintained in a bed through which the recirculating liquor flows. This obviates the necessity of maintaining the product in suspension and permits the formation of larger crystals. This type of design is used for $(NH_4)_2SO_4$ and may produce crystals several millimeters in diameter. The limitation in size of crystals produced is dependent upon the fundamental rate of crystal growth. The necessity of a large enough chamber to maintain a settled bed of crystals, the separate removal of crystals and mother liquor, and the auxiliary withdrawal of the excess nuclei, obviously increases the size of equipment and the complication of its operation. The continuous type as shown in Fig. 3(b) is readily subject to multi-stage design for increased economy of operation when large volumes of solutions are to be cooled. All three vacuum types can be used either without a booster (steam jet vapor compressor) as in Fig. 3(a) and 3(c) or with a booster as in Fig. 3(b), for cooling to temperatures at which the saturated vapor arising from the solution cannot be condensed with the available cooling water.

Recent German literature has mentioned two designs of continuous multi-stage vacuum crystallizers of which Fig. 4 is diagrammatic.[6] These designs by Otto Meyer are said to use 21 to 25 stages when separating KCl crystals from an aqueous NaCl solution. The screen analysis above for sample B is given as the performance for 21 stages arranged as shown in Fig. 4(a). The screen analysis for sample A is attributed to normal production in a crystallizer having four stages in which the Miers principle was used with an attempted 4 to 6 deg. F. supersaturation. The total cooling range is assumed to be the same in both examples, namely 208 deg. F. to 68 deg. F. Fig. 4(b) shows a horizontal variation of Fig. 4(a), the crystals being carried along toward the final stage by means of the screw conveyor which passes continuously through submerged openings in the baffles between stages. No mention is made in regard to the salting-up of the equipment of either design. It is apparent that both of these designs are capable of operation within the Ross hypothesis and should give satisfactory results.

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Dissolving and Leaching As Diffusional Operations

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Principles of dissolution operations and equipment design have been evolved largely by empirical methods and the theories of diffusion have had little influence on their development. Herein the author treats of dissolution as a diffusional operation and shows its close relationship to liquid-solid mixing and mechanical separation. *-Editors.*

DIFFUSION AS A CONCEPT in dissolving and leaching operations is not new in chemical engineering, but relatively little has been published on the subject and quantitative data on the rate of extraction of different materials are meager. Hence it is easy to understand why operating procedures and the design of equipment in industries employing these diffusion processes are determined largely by empirical methods. In this article an attempt will be made to outline briefly the diffusional concept as related to liquid-solid extractive operations. Theory, equipment and design will be treated.

Both dissolving and leaching, as well as other related liquid-solid extractive operations, are characterized by the fact that their speed or rates depend, to a greater or less extent, on the diffusion of materials through fluid films. In the extraction of soluble material from insoluble matter by means of a liquid, the dissolved solid must diffuse through the interstices of the inert solid and then through the adjacent liquid film (which is saturated with solute) before it can come in contact with the main body of the solvent and be diffused by various means. The dissolving of completely soluble crystalline solids is somewhat different. Here the soluble component diffuses from a solid interface having a definite space lattice pattern instead of through inert, insoluble material.

DIFFUSIONAL CONCEPT

Since all dissolution operations are characterized by diffusion of the soluble material in the direction of the body of the solvent, the question now arises: What are the factors that govern the *rate* of this diffusion? This leads to a discussion of the theoretical development of the diffusional concept as applied to liquid-solid extraction.

The rate at which a dissolved substance diffuses in solution was formulated by Fick in 1855 in the following form:

$$ds/dt = -DA(dc/dx)$$

where s is the quantity of solute at time t, A is area through which the solute diffuses, dc is the salt concentration change, X is the distance element, and D is the coefficient of diffusion. Stated quantitatively, the coefficient of diffusion is the amount of solute that will cross 1 sq.cm. of cross section in a unit of time if the concentration change per centimeter in a direction perpendicular to the cross section is unity. All other motions except molecular movement are excluded; that is, the system is theoretically kept absolutely motionless and at a constant temperature. The law is stated for diffusion that takes place in one direction only.

Weber, however, showed that the diffusion constant defined the process of diffusion after the salt was in solution but did not clarify the process by which the salt dissolved before it was able to diffuse. He also showed that this constant decreased with increased salt concentration.

The thory of film diffusion in connection with the solution of solids, however, was soon formulated by Noyes and Whitney.[1] Their law states that the rate of dissolution of the solid, dc/dt, at any instant is directly proportional to the difference between the concentration of a saturated solution, C_s, and the concentration, c, existing in the solution at time t:

$$dc/dt = k(C_s - c).$$

The area variable was not included in the above equation, which assumes that a very thin film of saturated solution forms at the surface of the solid and that the rate at which the solid dissolves is controlled by the rate of diffusion from this saturated layer into the main body of the solvent. This law, without any assumptions regarding the mechanism by which dissolution takes place, has been substantiated experimentally.

Later Brunner and Tolloczko showed that the value of the constant k, in the Noyes-Whitney equation depended upon such factors as solid surface exposed, solvent velocity across the solid surface (rate of stirring), temperature of the solvent and surface structure of the solid. Thus, the loss in weight of the dissolving solid in a unit of time, or mass transfer rate, is a direct function of the specific diffusivity of the salt in the solvent, the area of the particle and of the difference in concentration of the salt on either side of the liquid film. The side of the film in contact with the solid material is assumed to be saturated while the opposite side has a salt concentration the same as the main body of the solution. The rate of solution is thus inversely proportional to the effective film thickness. With any given system, the diffusion rate constant varies with the temperature because of the effect of this on diffusivity and kinematic viscosity and with agitation and eddying, since these act to decrease the film thickness.

About this time Nernst postulated that at the boundary surface of the different phases the equilibrium is set up at a practically instantaneous velocity as compared to the rate of diffusion. The original Nernst-Brunner theory assuming the existence of a stagnant film at the interface between the two phases across which material is transported by molecular diffusion only, has been critically analyzed by a number of investigators. It is probably an over-simplification of the mechanism of mass transfer. Nevertheless, wide use is still made of the concept of effective film thickness in which resistance to molecular diffusion is assumed to be dependent upon a stagnant film of fictitious thickness at the phase boundaries.

CUBE ROOT LAW

An outstanding advance in the study of the effect of variables on the rate of solution was made in 1931 by Hixson and Crowell.[2] These investigators made a quantitative approach to the study of agitation in which the diffusion rate constant served as an index to the effectiveness of agitation. The results gave not only an indication of the degree of agitation produced, but also a numerical value, the dissolution constant, for calculating the rate of solution of solids in liquids. These authors showed that with uniform agitation and a constant shape of solid, the velocity of solution will vary directly as the surface of the solid changes. This new law, termed the "cube root law," was obtained by integrating the equation

$$-dw/dt = -kA(C_s - c)$$

after expressing the surface area, A, of the dissolving solid in terms of its weight, w, at time t. The exact expression of the law, in which the cube root of the weight of solid appears as a term, is algebraically complex.

In 1933, Hixson and Wilkens[3] gave a valuable experimental verification of the "cube root law" by studying the performance of agitators in liquid-solid chemical systems. More recently, Hixson and Baum[4] derived a simplified form of the cube root law which gives

results comparable with the exact expression. The existence of a critical Reynolds number for agitation systems was also confirmed. This contribution is of considerable significance, since it indicates a practical method for applying the dissolution constant to the problem of designing and determining operating characteristics of mixing equipment.

Having reviewed thus the theoretical development of the concept of molecular diffusion as applied to liquid-solid dissolution, it is now time to consider the practical aspects of the problem and the relationship of mixing and dissolving operations.

MIXING AND DISSOLUTION

An analysis of the dissolution operations in plant practice shows that with few exceptions there are three phases involved: (1) mixing in its broad sense, (including agitation, turbulence and eddying) as a step necessary to shorten the time and increase the efficiency of the dissolving mechanism; (2) dissolution itself, including dissolving, leaching and the other types previously defined; (3) separation of the insoluble inert materials from the dissolved solids.

In the engineering approach to plant problems of this nature, it is important to consider carefully each of these three factors. The unit operations of mixing and dissolution are especially closely related and in actual practice they can seldom be separated. For these reasons, this article will deal with the operations of liquid-solid mixing and separation as well as with dissolution.

Mixing in liquid-solid extractive operations has for its object speeding up the dissolution of the solid and molecular diffusion from the saturated liquid film adjacent to the solid phase into the body of the liquid. The net effect of agitation and eddying is to decrease the thickness of this liquid surface film. This gives the same effect as increasing the interfacial surface of the solid exposed to the solvent. This is important, for the dissolving action is directly proportional to the surface exposed.

An excellent illustration of the effect of this surface exposure on the speed of dissolution is given by double decompositions in which dissolved materials react to form a precipitate. Unless proper precautions are taken, this reaction product may precipitate on the surface of the dissolving solid to such an extent as to make it virtually insoluble. Methods used to prevent this condition in the manufacture of strong phosphoric acid by the wet process at Trail, B. C. have been given by Weber.[8]

Hixson and Wilkens in 1933[9] conducted experiments on the performance of agitators in liquid-solid chemical systems and demonstrated that in free rotational agitation, the effects of stirrer speed, size of equipment and fluid viscosity were very great. Baffles slowed down the fluid flow and shallow vessels gave more effective agitation than deep ones having the same stirring speed.

However, since the gain in agitation from increased stirring speed is small when the straight-line relationship is approached, and since the variation of large scale equipment is not great, the variable of viscosity becomes very important in agitation efficiency. In plant practice, viscosity is usually lowered by application of heat.

Rate of solution was found to be greater in a free rotational than in a baffled system at speeds of 100-300 r.p.m. The freely rotating turbine was found to be more effective than the propeller under the same conditions. In the higher range of 300-500 r.p.m. the most effective agitation was obtained from a turbine operating in a fixed central deflecting ring. Power consumption per unit volume of liquid undergoing agitation increased rapidly as the size of the system increased.

Some of the variables affecting mixing and hence dissolution in the free rotational agitation of liquid-solid systems include: (1) size of agitator; (2) position of agitator; (3) angular velocity, r.p.m.; (4) temperature; (5) shape of vessel; (6) shape of agitator; (7) volume of liquid; (8) location of solid; (9) piling effect of solids; (10) size of solid particles; (11) size distribution; (12) layer or stratification effect due to low intensity agitation.

All in all, other than the previously mentioned experiments by Hixson and co-workers, comparatively few engineering data have been collected to reduce into mathematical equations the factors governing the degree or speed of mixing in liquid-solid extractive systems.

Table II—Factors Affecting Rate of Dissolution and Distribution in Soluble Liquid-Solid Systems[1]

Factors concerning solid:
- Average surface per unit of weight
- Uniformity of size distribution
- Shape characteristics of particles
- Homogeneity of particles
- Diffusion coefficient for given liquid
- Incipient fractures, gas films, etc.

Factors concerning liquid:
- Agitation in contact with solid surface
- Temperature
- Concentration of dissolved solid
- Viscosity

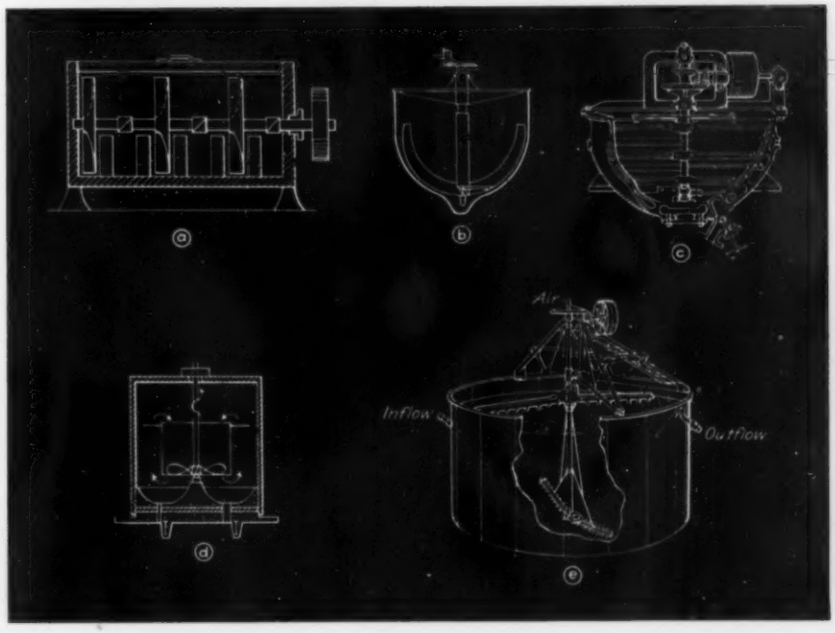
Factors concerning both liquid and solid:
- Chemical nature of liquid and solid
- Relative densities
- Proportion of solid and solvent

Distribution:
- Intensity and uniformity of agitation
- Type of generating motion
- Shape of container
- Type of deflecting walls or barriers
- Total volume of system
- Generating forces
- Changes in character of agitation
- Degree of magnification

[1] Compiled by Hixson and Crowell.

White,[5] however, has supplied data from which, in the case of cylindrical tanks with unimpeded swirl, a prediction of power requirements of flat-paddle agitators can be made, and Büche[6] has outlined a method for designing a paddle agitator for a given purpose. The theory of "streamlining" in agitation by short-circuiting in continuous-flow mixing vessels in series has been treated by MacMullin and Weber.[10] Brothman and Kaplan[7] have shown that the degree of mixing is related to the power input per unit volume and have plotted it against a "shear index" or measure of work output of the paddle per unit input.

Fig. 1—Types of mixers commonly used in dissolving operations: (a) paddles with intermeshing-stationary fingers; (b) horseshoe type heavy duty mixer; (c) double motion paddle mixer in kettle; (d) propeller in draft tube; (e) air-lift agitator with scrapers, used for slow mixing and with large volume of slurry



Since the unit operation of mixing in liquid-solid extractive systems is so empirical, an enormous number of different type mixers have been developed by equipment manufacturers and others. Valentine and MacLean,[5] however, have found that from the standpoint of physical characteristics of the materials to be mixed, some 40 distinct types will cover every mixing operation in every industry. Such a classification of mixers applicable to large-scale batch liquid-solid dissolution systems is given in Table I.

In industrial processes, one or more separation operations usually follows dissolution of a solid in a liquid. The one outstanding exception to this is, of course, the simple dissolving of a completely soluble material. Otherwise, it is usually desirable to separate the insoluble inert material from the solution containing the dissolved solid. The separation operations as such have little or no influence on the actual rate of diffusion or dissolution. They are purely mechanical in action. For example, filtration is often carried out in conjunction with dissolving a soluble material from an inert solid, but it

Table I—Preferable Types of Mixers for Large-Scale Liquid-Solid Batch Dissolving[1]

Consistency[2]	Character of Solids[3]	Example	Slow Leaching	Fast Leaching		Dissolving	
				Ordinary	Maximum	Slow	Fast
Thin (Having an apparent viscosity up to 100 c.p. when placed under high rate of shear)	Low-gravity difference (not over 1)	Salts in water	Air Outside circulation Blade paddle mixers Gate type mixers Intermeshing stationary finger paddle mixers Propellers with vertical shaft Propellers in tank side Propellers in draft tube Simple turbine mixer Turbine with stationary deflecting blades	Paddle with intermeshing stationary fingers Propeller in draft tube	Turbine mixer with stationary deflecting blades Propeller in draft tube		Simple turbine mixer Turbine mixer with stationary deflecting blades Propeller in side of tank Propeller in draft tube
	High-gravity difference (over 1)	Sodium sulphate in water	Propeller in side of tank Propeller in draft tube Simple turbine mixer Turbine mixer with stationary deflecting blades	Propeller in draft tube Turbine mixer with stationary deflecting blades	Turbine mixer with stationary deflecting blades		Simple turbine mixer Turbine mixer with stationary deflecting blades
	Fibrous (as cellulose)	Nitrocellulose in solvents	Air Straight arm paddles Gate type mixers Paddles with intermeshing stationary fingers Propeller in tank side Propeller in draft tube Simple turbine mixer Turbine mixer with stationary deflecting blades	Propeller in draft tube	Turbine mixer with stationary deflecting blades	Outside circulation Straight arm paddles Paddles with intermeshing stationary fingers Propeller in tank side Propeller in draft tube Simple turbine mixer Turbine mixer with stationary deflecting blades Traveling paddle	Simple turbine mixer Turbine mixer with stationary deflecting blades
Medium (Having an apparent viscosity up to 2500 c.p. when placed under high rate of shear)	Low-gravity difference (not over 1)	Leaching diatomaceous earth	Straight arm paddles Gate type mixers Paddles with intermeshing stationary fingers Propeller with vertical shaft Propeller in tank side Propeller in draft tube Traveling paddles Air-lift agitator	Same as for thin	Same as for thin		Simple turbine mixer Turbine mixer with stationary deflecting blades Propeller in tank side Propeller in draft tube
	High-gravity difference (over 1)	Barytes bleaching	Simple turbine mixer Turbine mixer with stationary deflecting blades Air-lift agitator	Same as for thin	Same as for thin		Turbine mixer with stationary deflecting blades
	Fibrous (as cellulose)	Cellulose acetate in acetone	Straight arm paddles Paddles with intermeshing stationary fingers Propeller in tank side Propeller in draft tube Simple turbine mixer Traveling paddles	Same as for thin	Same as for thin	Outside circulation Straight arm paddles Paddles with intermeshing stationary fingers Propeller in tank side Propeller in draft tube Simple turbine mixer Turbine mixer with stationary deflecting blades Traveling paddles	Turbine with statonary deflecting blades
Thick (Apparent viscosity over 2500 c.p. and up to 200,000 c.p. when placed under high rate of shear)	Low-gravity difference (not over 1)	Grain mash	Straight arm paddles Gate type mixer Paddles with intermeshing stationary fingers Simple turbine mixer Turbine mixers with stationary deflecting blades Air-lift agitator Traveling paddles	Paddles with intermeshing stationary fingers Simple turbine mixer Rake mixer Traveling paddle			
	High-gravity difference (over 1)	Leaching copper oxide	Paddles with intermeshing stationary fingers Simple turbine mixers Turbine mixers with station ary deflecting blades Air-lift agitator Traveling paddles	Paddles with intermeshing stationary fingers Simple turbine mixer Turbine mixer with stationary deflecting blades Traveling paddles		Straight arm paddles Paddles with intermeshing stationary fingers Simple turbine mixers Turbine mixer with stationary deflecting blades Air-lift agitator	
	Fibrous	Cellulose acetate in acetone	Propeller with vertical shaft Propeller in tank side Propeller in draft tube Traveling paddles	Straight arm paddles Paddles with intermeshing stationary fingers Propeller with vertical shaft Propeller in tank side Propeller in draft tube Traveling paddles			

[1] The least desirable mixer is listed first. Modified after Valentine and MacLean, Chemical Engineers' Handbook, 2nd Ed., 1941. For similar data on small-scale batch mixing and continuous mixing, refer to the same authorities.

[2] A large-scale batch is here defined as any quantity above 25,000 gal. at thin consistency and more than 10 percent of this amount at very high consistency.

[3] Refers to specific gravity difference between liquid and solid. System is based on mixing one solid in one solvent.

usually takes place only *after* dissolution has been substantially completed. Classification is probably the only case in which dissolution and mechanical separation occur simultaneously in the same equipment. In spite of this, a brief consideration is here given to the separation operations simply because the design of equipment for industrial liquid-solid dissolution is often dictated, or at least modified, by the problems of separation as much as by those of mixing.

An interesting illustration of the inter-relationship of dissolution and related operations is shown by ball mill closed-circuit wet grinding. This relatively simple operation is capable of accomplishing a quadruple function: grinding, mixing, dissolution and separation. Grinding is necessary in order to break down physically and separate the interlocking soluble and inert values. Mixing is accomplished at the same time and is necessary for dissolution, which takes place simultaneously with grinding and mixing. And finally there is the separation. An example of combined grinding and dissolution occurs in the cyanidation process in which cyanide liquor serves as the grinding solution in the ball mill. Details of equipment and operation of wet grinding are given by Anable.[5]

Data will not be given here on the theory of mechanical separation as applied to liquid-solid systems, although considerable details on design of equipment have been well worked out.[4]

Having mentioned briefly the present status in respect to the design of equipment for both mixing and separation of liquid-solid systems, we can now understand why information on the dissolution operation as a unit is largely empirical.

EQUIPMENT FOR DISSOLUTION

Although a large number of specific factors affecting the rate of dissolution and distribution in soluble liquid-solid systems have been tabulated by Hixson and Crowell[3] (see Table II), quantitative data on the rate of extraction of different materials are practically nonexistent. Consequently, the size of apparatus and time of contact in the various industries employing liquid-solid extraction processes are largely determined by experimentation and experience, and the diffusional concept seldom bears much weight. It is hoped that at least the influence of the three outstanding factors that control the rate of transfer (concentration of dissolved material, surface area of solids, and agitation) can be isolated and applied to the problems of equipment design. Definite steps are now being made in this direction.

Types of equipment usually employed for liquid-solid dissolution and separation can be divided into two categories: (1) those used when the solids are relatively coarse; (2) those used when the material is in a relatively fine state of sub-division.

Equipment used for coarse solids may include anything from open tanks or vats with false bottoms to pressure vessels and diffusion batteries in series. These often operate on the percolation principle. Rake classifiers are also used, often of the continuous, counter-current, multi-deck type.

Counter-current extraction can be used on a series of open tanks, each of which contains stationary solid in various stages of extraction. The material stays in one tank until it is completely extracted, and tanks are charged and discharged one at a time. This arrangement is called an extraction battery and is sometimes known as the Shanks process. It was first applied to the leaching of black ash in the LeBlanc soda process and is now used for producing tan-bark extracts and in the nitrate fields of Chile.

When the Shanks counter-current system is applied to materials through which water will not percolate by gravity head but must be pumped by pressure, the system is then known as a *diffusion battery*. Closed vessels instead of open tanks are used. It is widely used for preparation of tanning extracts, leaching of black ash in the soda and sulphate process for paper pulp, and for extracting sugar from beets.

Rake and spiral classifiers are used for leaching granular materials which will not remain in suspension and which can be leached by surface washing. Several decks are usually used, and the solid and liquid flow is counter-current. The single-deck rake apparatus usually consists of a settling box in the form of an inclined trough with the upper end open, in which are placed mechanically operated rakes which carry the quick-settling granular material to the point of discharge at the open end. The feed enters continuously from a distributing trough near the overflow end. The quick-settling particles sink to the bottom of the tank and are carried up the inclined deck by the reciprocating rakes. This granular product emerges from the liquid at the upper end and the excess solution drains off. The mesh of separation between discharge and overflow solids is determined by rake speed, overflow dilution and slope of tank bottom.

The Dorr bowl classifier is used when a cleaner rake product is desired, where the overflow product is to be of extremely fine size, and where the solution overflow capacity is large in comparison with the raking capacity. The Dorr multi-deck, continuous counter-current classifier consists of a series of two or more Dorr classifier mechanisms connected and driven from a continuous driving mechanism. Detailed data on Dorr classifiers are given by Anable.[5]

Table III—Classification of Liquid-Solid Extractive Equipment

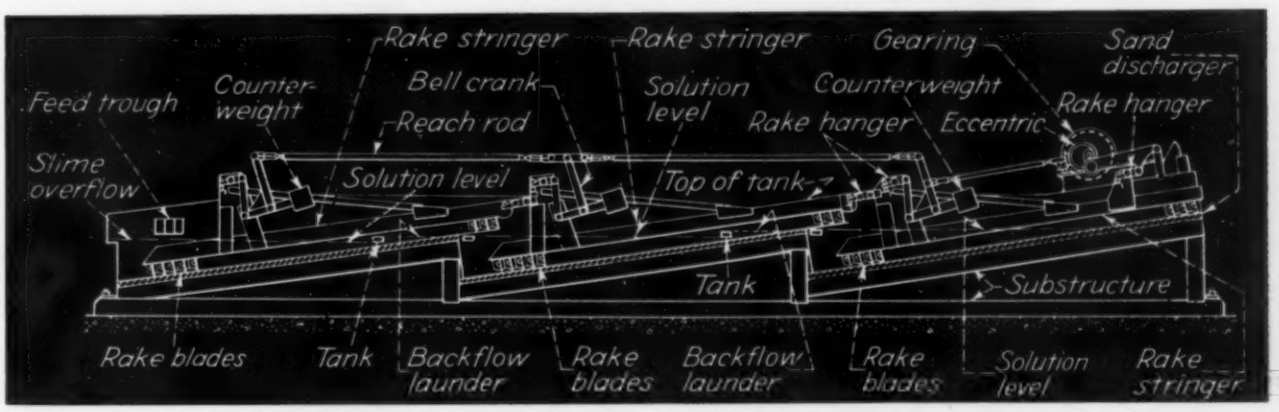
For treating coarse solids:
- Open tanks and vats
- Diffusion batteries
- Single-deck rake classifiers
- Multi-deck rake classifiers

For treating fine materials:
- Agitators
  - Simple
  - Pachuca tanks
  - Dorr agitators
- Thickeners

TREATMENT OF FINE MATERIAL

Liquid-solid dissolution of fine material can easily be accomplished by agitators of various types. For most materials of average density, a 48-mesh size is about as coarse as can be kept in suspension, although grinding

Fig. 2.—Principles of the Dorr multideck, acid-resisting type of washing classifier



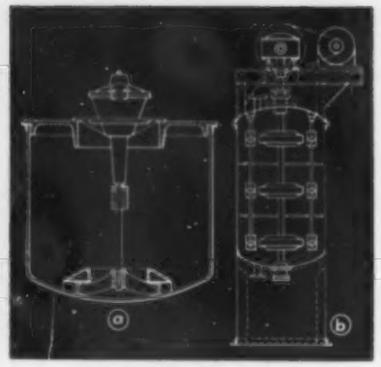


Fig. 3—(a) Turbo-mixer; (b) continuous flow turbo-disperser

to a finer particle size is often practiced in order to speed up the release of the soluble material. The economics of grinding and the ease with which the soluble components are released will largely determine the degree of grinding.

The Pachuca tank is a tall cylindrical vessel with a conical bottom. An open tube extends through the center of the tank and the nozzle of an air-jet lift is located at the bottom of the tube. Both liquid and solid are lifted together through this tube by the air-jet lift and sufficient circulation is thus produced to keep the solid in suspension.

The Dorr agitator is widely used for dissolving and separating liquid-solid systems, either by batch or continuous operation. This apparatus is a flat-bottom tank having a simple vertical tube with an air-jet lift in the bottom. The tube also serves as a shaft and carries a set of arms both at the top and at the bottom of the tank. Material on the bottom is scraped inward toward the air-jet lift, then it goes upward through the shaft to be distributed through perforations in the top arms.

Continuous counter-current decantation (C.C.D.) is the term applied to a continuous system of washing finely-divided solids to free them from liquids containing dissolved substances. The process consists of a series of continuous thickeners so arranged that the solids pass through them in series, being diluted after each settling by a weaker solution overflowing from subsequent thickeners. The Dorr thickener, most widely used settling apparatus, consists of a large-diameter, flat-bottom tank, having a central shaft on which is a set of slowly rotating arms. The slurry is fed into the central well as quietly as possible. Clean liquor overflows into a launder around the circumference of the tank, and the arms slowly scrape the settled insoluble material to the center where it is discharged.

This C.C.D. system can be used in chemical processing whenever a pulp, consisting of finely-divided, "settleable" solids and a solution, is to be separated and the solids need to be washed thoroughly. It is used for the manufacture of aluminum sulphate, caustic soda from causticized lime, and phosphoric acid by the wet process. Modifications include (1) the simple C.C.D. flow; (2) double-stage reaction with an intermediate stage of thickening; (3) intermediate-agitation flow; (4) continuous counter-current decantation flow with filter at the end; (5) the Dorr washing-tray thickener.

SOURCES OF INFORMATION

Excellent summarized information on the general subject of washing, classification, sedimentation, etc., has been provided by Anable[9] and on filtration by Irvin and others.[10] For methods of calculating leaching operations in terms of the number of theoretical contacts, reference should be made to Baker,[11] Elgin,[12] and Ravenscroft.[13] Donald[14] has classified and described in detail various types of percolation equipment. Other sources of information on various phases of liquid-solid dissolution and separation have been mentioned throughout the text.

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Atmolysis

SEPARATION of the constituents of a gaseous mixture by methods based on diffusive properties of gases of different molecular weights is known as atmolysis. In "Mechanical Separation of Gases," C. G. Maier has reported on an extensive series of tests carried out at the Bureau of Mines.* The report is quite comprehensive giving historical development, theoretical principles as well as descriptions of the atmolyzer and the results obtained from its use. This extremely brief abstract is intended merely to review an interesting "Diffusional Operation." The original publication should be consulted for detailed information.

The desire for a source of pure, cheap hydrogen for certain metallurgical and chemical purposes leads directly to an incentive for technical utilization of diffusive properties, as the diffusivity of hydrogen is one of its outstanding physical characteristics. It should be pointed out that the speed of diffusion processes is frequently the subject of considerable misapprehension and the conclusion that diffusion is inherently an extremely slow process is not borne out upon closer examination of the phenomena.

Theoretical considerations lead to three indicated requirements for the construction of the atmolyzer: (1) Parallel ducts in which the static pressures of gases or vapors flowing therein may be accurately controlled; (2) An interconnection of a size only small enough substantially to prevent hydrodynamic flow from duct to duct within the limitations of permissible sensitivity of control of the static pressures; (3) A third gas or vapor utilized as a sweep gas in one duct to maintain the maximum concentration gradient of the components to be enriched or separated. In most cases this will preferably be an easily condensible vapor, such as steam, so that the enriched gases may be separated by cooling and condensing the diluent vapor. The molecules of the third vapor provide "canals" of a size comparable to mean free path of the diffusing gas. Therefore the vapor acts as a septum, incapable of being plugged and instantly renewable.

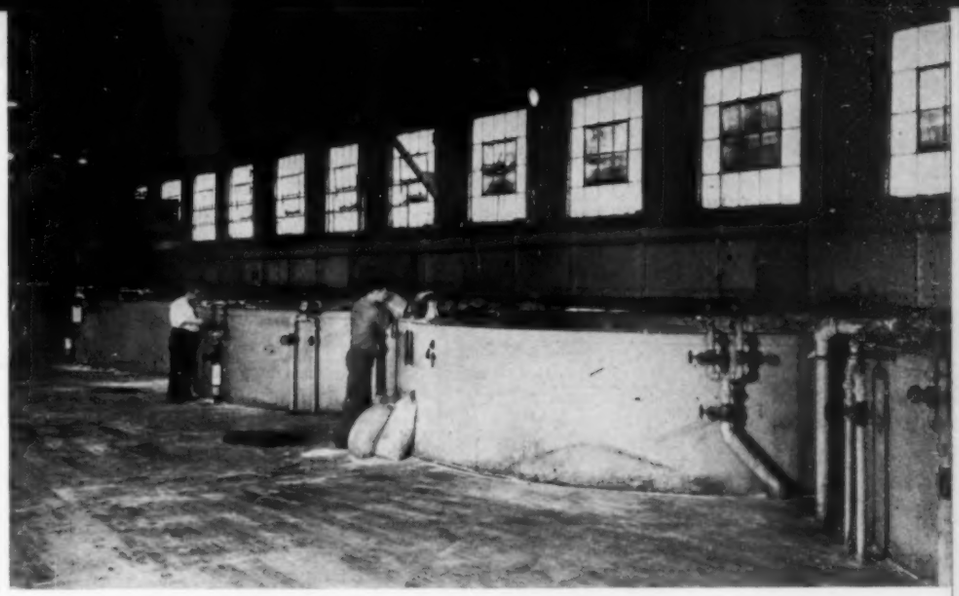
On the basis of many experiments, the author concludes that total fuel requirement should not exceed that required for 1,000 lb. of primary steam per 1,000 cu.ft. of hydrogen recovered from a feed gas with an initial content of 27 to 33 percent H_2.

A method has been developed for converting methane-air mixtures into a re-formed gas containing carbon monoxide, nitrogen and about 30 percent hydrogen. Such a mixture could serve as a source of hydrogen. With suitable recovery of heat in the condensed vapor, the author believes that 1,500 to 1,850 cu. ft. of methane will yield not only the hydrogen but also the fuel needed to produce 1,000 cu.ft. of hydrogen.

The author is convinced that the method is theoretically correct and that future work should be directed along the lines of reducing the process disclosed to a commercially practical operation.

* Bureau of Mines Bulletin 431; Available from the Superintendent of Documents, Washington, D. C. Price 20 cents.

Reprints of this 48-page report are available at 50 cents per copy. Address the Editorial Department, *Chem. & Met.*, 330 W. 42nd St., New York, N. Y.



Saponification of the fats is carried out in huge kettles, the process requiring several days. Here the "full-boiled" process is employed

Modern Soap and Glycerine Making

JAMES A. LEE *Managing Editor, Chemical & Metallurgical Engineering*

***Chem. & Met.* INTERPRETATION**

For more than half a century the Manhattan Soap Co. has been producing soap and glycerine. Chemical engineers will be interested in this article describing the processes used and the recent modernization of the entire plant which was done to increase output, to improve quality of product, to reduce manual labor, and to keep up with increasing civilian and military demands.—*Editors.*

FIFTY-TWO YEARS AGO a small plant on Manhattan Island produced its first cake of soap. Frank G. Burke organized the company and named it for the island on which it was located. Sweetheart Soap, the principal product of the Manhattan Soap Co., was one of the first nationally advertised toilet soaps. In 1929, the soap plant was moved to its present site at Bristol, Pa., where it has continued its growth. Since then, the size of the plant has been increased several times, the most recent expansion occurring in 1940-41, at which time the entire plant was modernized. The production facilities were laid out and designed in order to increase output and efficiency and to improve quality of products. Modern materials of construction for equipment were specified and conveying equipment was installed so as to reduce manual labor to a minimum. The packaging and shipping building was completely equipped with automatic wrapping, labeling, and packaging machinery.

The manufacturing operations really start with the raw materials. Unusual precautions are taken in their selection, and the purifying and bleaching treatments are stressed in order to assure highly refined soap products. Tallow and coconut oil are stored out of doors in large steel tanks equipped with steam coils. When a batch of oil or tallow is required steam is introduced and the temperature of the material is raised to 100-110 deg. F. to permit pumping. The caustic soda is stored in steel tanks in the processing buildings.

The same equipment is used for refining and bleaching both tallow and oil. There is one tank for refining and two for bleaching. The refining tank has a cone-shape bottom and is equipped with steam coils, a motor-driven agitator near the bottom, a swivel pipe for removing refined stock, and a piping system on the top for the distribution of caustic and brine into the tank. Directly under the refining tank is a rectangular tank for holding the foots from the refining operation. The bleaching tanks are equipped with steam coils, cooling coils, and a motor-driven propeller near the bottom which supplies agitation. A removable canvas cover with an attachment for a suction fan leading to the outdoors serves the purpose of controlling the dust occurring when the clay and carbon are dumped into the kettle. Since temperature control is so important in bleaching, it is desirable to have dial thermometers which may be read at a glance and from a distance. A plate and frame filter press, a condensate tank, and several pumps complete the equipment in this department.

Tallow and coconut oil for use in making toilet soaps require decolorization or bleaching. Minutely divided suspended matter, colloidal bodies, and soluble coloring matter are subject to removal by adsorbent earths, the completeness with which this is accomplished is a function of the surface activity of the adsorbent.

These two raw materials are given somewhat similar treatments. Practice has demonstrated that better decolorization results may be obtained by first refining the material and then bleaching. As required the materials are pumped indoors into the refiner, diluted caustic is added to neutralize the free acids, and to remove any mucilaginous matter that may be present in the tallow or oil, whichever the case may be.

In the bleaching process different adsorbent combinations are used for the tallow and oil and they are bleached to different color standards,

Salt from the evaporators is separated in the centrifugal, washed, and is dumped onto a belt conveyor below, which carries it to wooden brine tanks

and then stored separately. A measured volume of tallow is charged into the bleach tanks, agitation started and heat applied. When a temperature of 150 deg. F. is reached the activated fuller's earth and activated carbon are added. The temperature is raised to about 240 deg. F. and the agitation continued. The temperature is maintained for a few minutes to drive off completely all moisture from oil, clay and carbon and then lowered to about 220 deg. F. By so doing, the tendency for color reversion in the stock is minimized. When the laboratory analysis indicates a satisfactory bleach has been obtained the tallow is ready for filtration.

The bleaching procedure for coconut oil is similar to that for tallow with the exception that much less of the bleaching agents are necessary.

The tallow or oil and bleaching agents are passed through a filter press and the clear filtrate flows by gravity to storage tanks on the floor below. When steaming the filter press, any stock extracted from the cake is retained in the condensate tank. Water is drained off and the stock is returned to the bleach tanks.

Saponification of the fats is carried out in huge soap kettles, the process requiring several days. While the practice varies in different plants, here the so-called "full-boiled process" is employed with several changes in order to remove as much of the glycerine as practical and to obtain a better color in the finished soap, notwithstanding the fact that additional labor and steam consumption add to the cost of the operations.

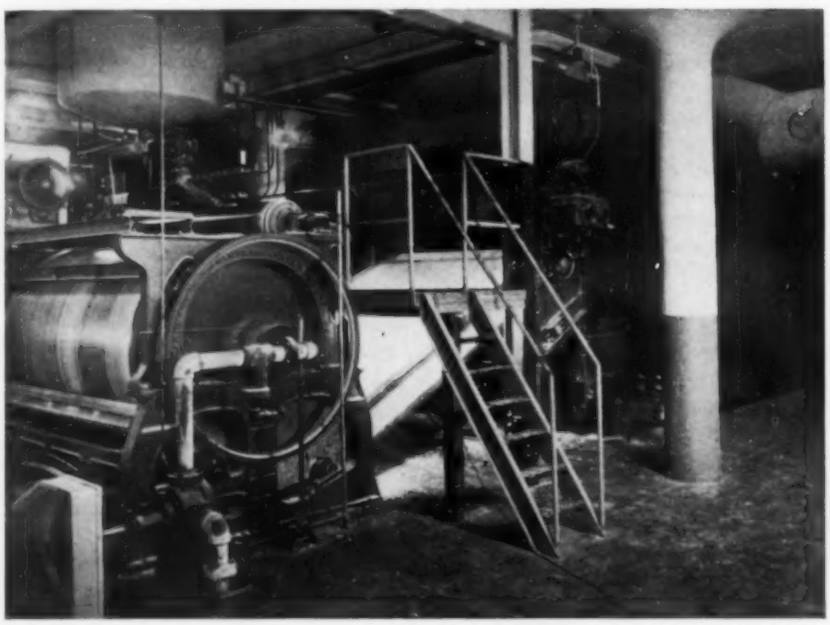
As required, measured volumes of refined tallow and coconut oil are pumped into the kettles. The open steam coils are turned on and just enough steam is admitted to agitate the fats gently. A moderately diluted caustic soda solution (5 to 10 deg. Be.) from the previous boiling operation is run in slowly. Gentle boiling is continued and after a period the mass begins to thicken due to partial saponification. When the operation is complete, the soap, glycerine and excess alkali are all in solution in the mass of soap and water in the kettle. It is necessary to separate or "grain out" the soap. For this purpose granular salt or a salt brine solution is added while the kettle contents are boiling. Boiling is continued for a short time after all salt has been added so as to assure thorough mixing of the salt solution throughout the soap. By addition of salt solution to the partially saponified soap, the soap which may have been dissolved in the water is thrown out. This is due to the fact that soap is practically insoluble in a salt solution of sufficient strength. The salt required to carry out this result in the lye is between 9 and 13 percent. The glycerine which has been produced by hydrolysis of the fat is also partially included in this lye. The separated soap forms a body at the top of the kettle contents, floating on the heavier "spent lye" solution, which contains the bulk of the water, some of the glycerine, and excess caustic. The contents of the kettle are allowed to settle and the heavier lye is drained from the bottom and pumped to storage tanks, where it is cooled before being sent to the glycerine department.

In the second "killing change," steam from the open coils in the kettle is turned on and water is added until the soap boils. Boiling continues until the soap is "closed." The remainder of the tallow and coconut oil for the batch is added to the kettle while it is boiling. Caustic is added in the same way as in the first killing change and graining then follows earlier procedure.

The purpose of the next (strong) change is to saponify completely the charge in the kettle by killing or saponifying the last traces of fat and oil. Steam and water are added and boiled until the soap is closed. Caustic is added slowly. After the completely saponified soap has been boiled a sufficient length of time it is again grained out. The contents of the kettle are settled and the lye is drawn off. As this lye contains a high percentage of caustic, it is used for saponifying another batch of fats.

At this point the soap is com-

Hot liquid soap flows into measuring tank and from there onto chilling roll. It is then carried through a tunnel dryer in which moisture is reduced from 30 to 14 percent



pletely saponified but contains an excess of caustic. In order to reduce the alkali content to a minimum it is therefore necessary to give the soap several washes using salt or brine as the graining medium. It is then ready for the "finish."

The finishing change is final and most important. Steam is turned on and the soap is brought to boiling. While boiling is proceeding, water is added until the soap closes. The object is to get the soap in such a condition that the darker soaps and impurities separate from the lighter soap and settle to the bottom of the kettle.

After the soap has been finished in the kettle and allowed to settle, there are two layers of soap of different appearance and total fatty acid content. The better, "neat," soap is the upper layer and below it is a softer, slightly darker soap in which coloring matter and other impurities (including salt and caustic) are concentrated. It is known in the industry as "nigre." This nigre is reboiled to remove salt and caustic, and is then used to make household laundry soap flakes.

The liquid white soap remaining in the kettles at a temperature of 200 deg. F. is passed through a Cuno pressure filter and then pumped through an asbestos-covered pipe line over a bridge to the finishing department in another building.

Here the hot liquid soap containing about 30 percent moisture is stored on the third floor in large tanks. As required it flows into a measuring tank and from there onto a chilling roll where it is solidified, being removed in thin ribbons by a doctor blade. It is then carried to a tunnel dryer. The soap is conveyed the length of the dryer three times at different heights. The tunnel is heated by fin-type steam coils. The drying operation reduces the moisture content to the neighborhood of 14 percent.

On leaving the dryer the soap is carried by a series of conveyors to any one of four bins located above the milling machines. A weighed charge is put into the amalgamator, perfume, and pigment are added and the mass thoroughly mixed. The soap is dumped into a pre-plodder and extruded on to a 5-roll mill. After further blending and working the soap is passed through the intermediate plodder from which it is extruded in spaghetti-like forms. These are carried by a belt conveyor to the final plodder. The soap is extruded from this machine in two 1½-in. diameter rods, which are cut into blanks of 5 in. in length and then pressed into the cakes of soap. The wrapping and packaging in cartons is done by ten lines of automatic machines and conveyors.

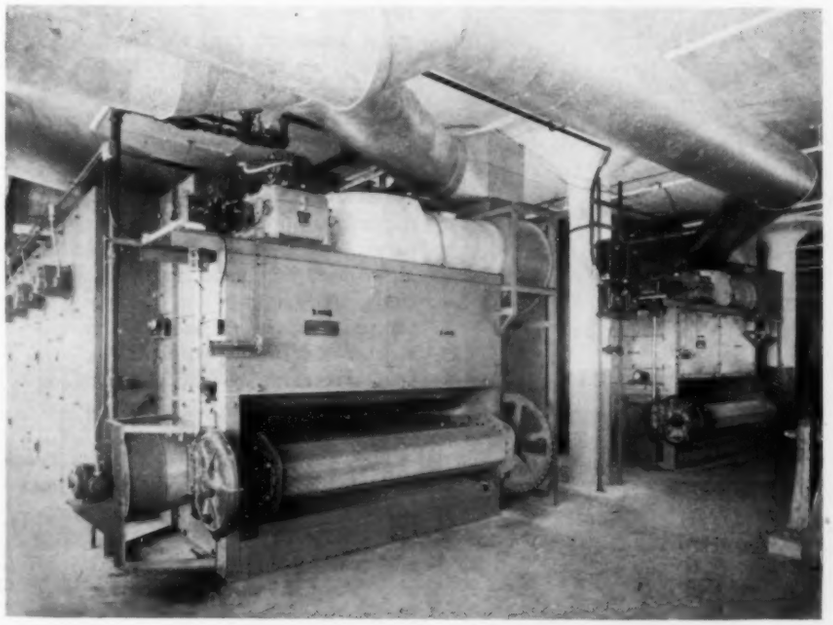
Returning to the nigre, or dark soap, which was separated from the lighter layer in the kettle, it is reboiled and settled to remove impurities and then filtered and pumped to the finishing building where it is stored in a tank on the top floor. From this tank it flows to a crutcher below and before flowing onto a chilling drum is mixed with such soap builders as tetrasodium pyrophosphate and sodium silicate. The soap is then chilled on the roll, and conveyed through a steam heated tunnel dryer, similar to the one used for the toilet soap. On leaving the dryer in the form of flakes the soap is conveyed by belt to a storage bin above. The Manhattan Soap Flakes are then packaged with automatic packaging equipment and conveyed to the warehouse.

So much for the production of the two principal products, toilet soap and soap flakes. In addition to these products there is the increasingly more important glycerine.

Lye removed from the soap kettles flows to large steel storage tanks on the outside of the building. The bottoms of these tanks are at an angle to the ground. They have been so designed to simplify cleaning. After 24 hours the cooled lye is pumped to cypress tanks nearby where it is treated with alum to coagulate and remove the soap and albuminous materials that may remain in solution in the lye at this stage in the process. The treated lye is then filtered through a press in the glycerine department in order to remove the coagulated im-

Soap is extruded in two 1½ inch diameter rods, which are cut into blanks of five inches in length and then pressed into the cakes of soap

Exit end of tunnel dryer. Soap is conveyed the length of the dryer three times. The dryer is heated by fin-shaped steam coils



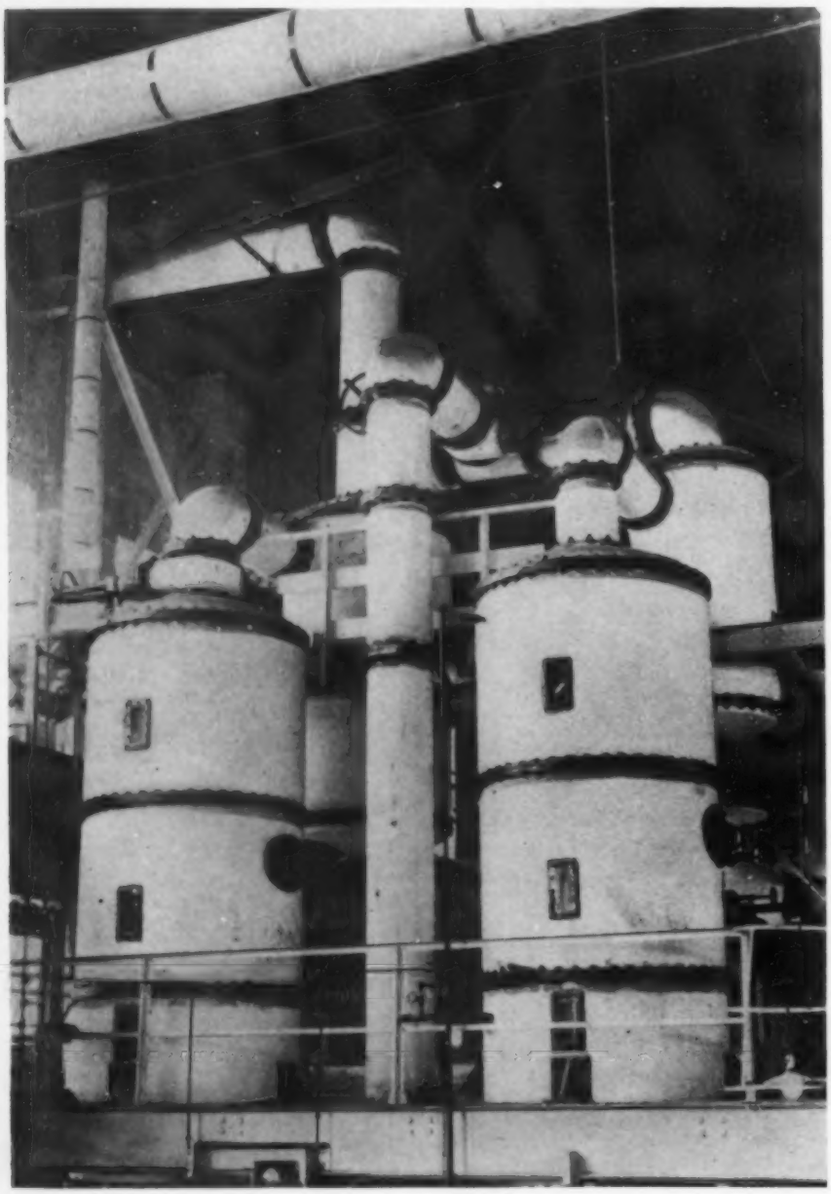
purities. The clear filtrate is run to cypress storage tanks outside. From there it goes to the evaporators. Owing to the high quality of fats and oils used at this plant, a second lye treatment is not necessary.

The glycerine is concentrated to about 40 to 45 percent in double-effect evaporators. The salt precipitates from the concentrating solution, collects in the drums below along with some glycerine and from there the slurry of salt and glycerine is blown to a slurry tank feeding the centrifuge. The slurry is kept in constant motion. Salt is separated in the centrifuge, washed, and is dumped onto a belt conveyor below which carries it to wooden brine tanks in the basement. The brine is reused in salting out soaps. The weak glycerine liquors leaving the centrifuge are returned to the evaporators for concentration to 80 percent.

The half-crude glycerine from the double-effect evaporator is discharged to settling tanks and is then fed to two single-effect evaporators for concentration to 80 percent soap-lye crude. This crude glycerine is sold to refiners.

As the perfume of a soap is an important factor in sale and use of a toilet soap, the perfuming operation in soap making is extremely important. The perfumery department occupies considerable space and is one of the show places in the plant.

Half-crude glycerine from double-effect evaporators is fed to two single effect for concentration to 80 percent soap-lye crude. This crude glycerine is sold to refiners



The strange appearing containers of essential oils from India, Africa, France, Italy, Spain, and the East Indies and other far away sources are in pronounced contrast to the modern laboratory setting where they are blended. Between 45 and 50 of these essential oils are blended and the mixture aged for several weeks to improve the odor characteristics before being added to the batch of Sweetheart Soap, the principal product of this plant.

The world conflict is rapidly putting a stop to the importation of these perfume oils. Already there is a noticeable trend toward the use of synthetic essential oils made in America and in all likelihood in 1943 this country will be entirely dependent upon the synthetic oils for perfumery of soap products.

The coloring matter in the soap consists generally of water-soluble or suspendible organic or inorganic pigments.

There are a great variety of antioxidants that may be used in soap to prevent the formation of randicity.

Like all process industry plants, this soap plant has its corrosion problems and must use special materials of construction to increase the life of equipment and to prevent the discoloration of its products. It has been found satisfactory to use nickel-clad steel for the section of the soap kettle that is generally above the liquor level. The glycerine-lye evaporators contain copper tubes, and 5 percent nickel steel castings. Red brass is used for all pipe lines handling salt brines or salt slurries. While coconut oil attacks plain steel, aluminum steam coils have been satisfactory in the storage tanks. Cypress wood tanks are used for storing certain of the glycerine-lye liquors.

The engineers have found that centrifugal pumps have proved most satisfactory for handling the soap and glycerine liquors.

Chemical laboratories in several departments in the plant exercise careful control over the operations. Raw materials must meet specifications, the refining and bleaching of the stocks are checked at various stages, and the saponification of the fats, glycerine recovery, moisture content of soap must be closely supervised by the laboratories.

The writer wishes to express his appreciation for the privilege of visiting this modern soap plant to Mr. I. Katz, vice president and general manager and to Mr. H. G. Fromm, plant manager of the Manhattan Soap Co.

Getting More Alcohol From Present Facilities

GUSTAVE T. REICH *Technical Director, Pennsylvania Sugar Co., Philadelphia, Pa.*

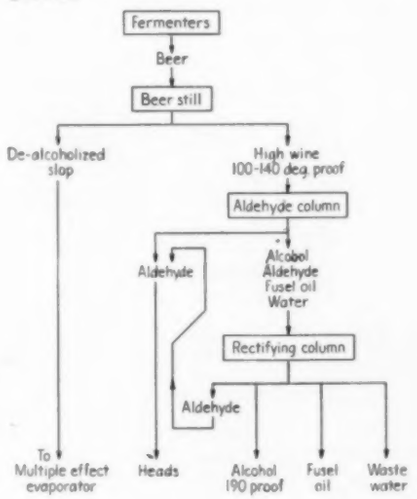
Chem. & Met. INTERPRETATION

Unprecedented demand for ethyl alcohol for use in explosives, synthetic rubber and solvents finds the fermentation industry handicapped by inadequate equipment. New construction involving the use of copper, stainless steel and aluminum is practically out of the question. Here, however, a resourceful chemical engineer shows how existing facilities in many distilleries can be adapted to increase the production of ethyl alcohol without the use of strategic metals. A stripping column of all-wood construction is one possibility he cites. You will find other suggestions equally as challenging.—*Editors.*

ONE OF THE SERIOUS PROBLEMS with which the chemical industry is confronted is the demand for increased production with inadequate equipment. Construction materials, especially for corrosive products are either scarce or not available at all. Therefore, processes must be improved or equipment constructed from substitute materials which are available in sufficient quantities. Likewise, improvements should be such that with increased production, the number of employees could be decreased owing to the increasing scarcity of labor.

Great demands are made upon the distillers for increased production of industrial alcohol, which is, and will continue to be required for the manufacture of explosives, synthetic rubber and solvents. Various suggestions have been propounded for the reconstruction of some whiskey distilleries and in the present article the author suggests methods whereby changes in the present equipment with available materials of construction would permit an increase in the production of industrial alcohol. The process, which has been described in *Chem. & Met.* (Vol. 44, No. 3, 1937), deals with the simultaneous evaporation of slop and distillation of alcohol.

Fig. 1. Conventional de-alcoholizing process



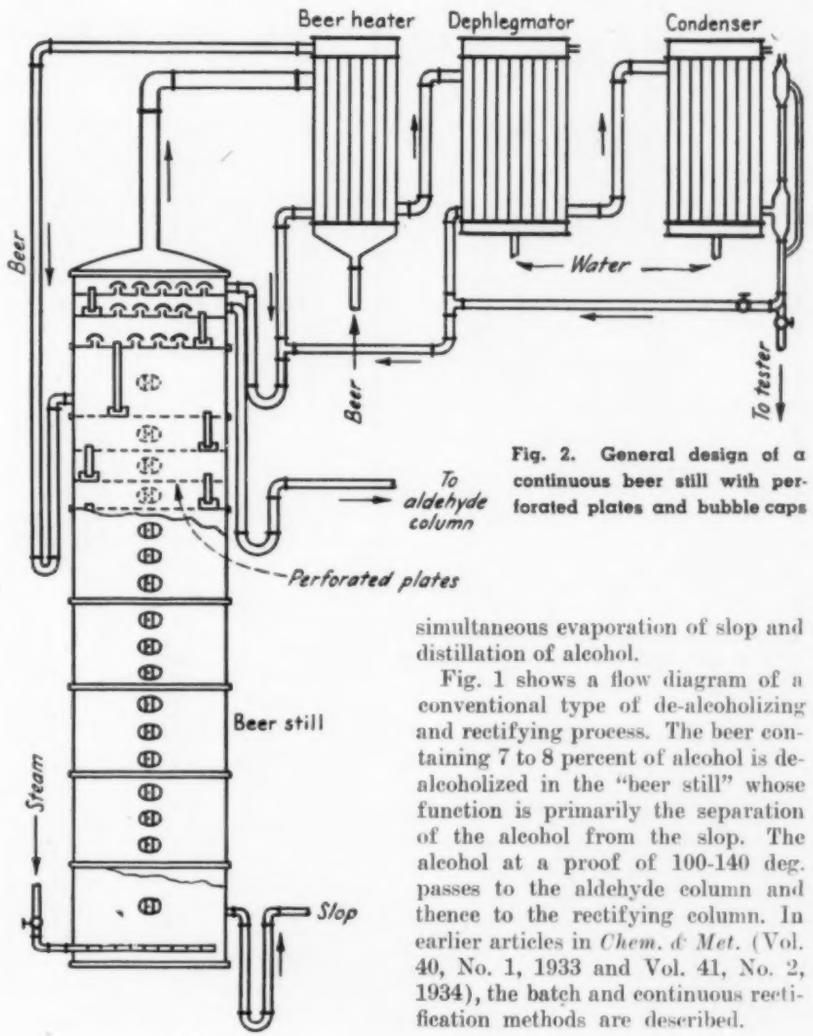
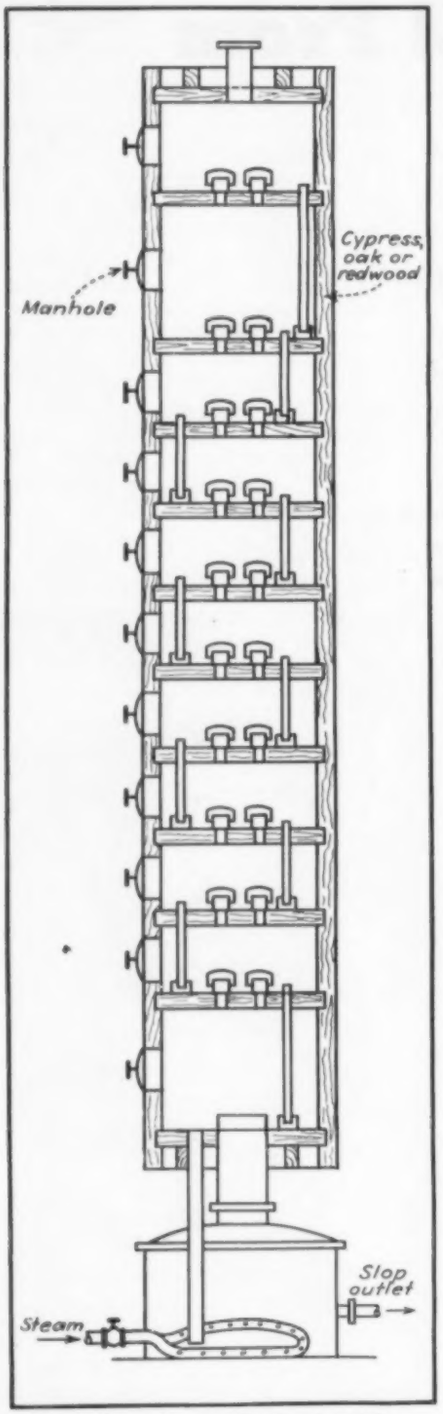


Fig. 2. General design of a continuous beer still with perforated plates and bubble caps

Fig. 1 shows a flow diagram of a conventional type of de-alcoholizing and rectifying process. The beer containing 7 to 8 percent of alcohol is de-alcoholized in the "beer still" whose function is primarily the separation of the alcohol from the slop. The alcohol at a proof of 100-140 deg. passes to the aldehyde column and thence to the rectifying column. In earlier articles in *Chem. & Met.* (Vol. 40, No. 1, 1933 and Vol. 41, No. 2, 1934), the batch and continuous rectification methods are described.



Beer still made completely of wood except for slop chamber

Fig. 2 shows a general design of a continuous beer still which usually has two types of plates. Above the beer inlet the plates are provided with bubble caps, while below the beer inlet the plates are perforated. Steam enters at the base of the column and the beer, consisting of alcohol, a very low percentage of acetaldehyde and fusel oil, water and solids, flows downward counter current to the steam and thereby becomes de-alcoholized. The slop is discharged at the bottom of the column and contains about 5-6 percent of solids by weight. On the average one bushel of corn yields 45 gal. of slop, containing 11.0-11.5 lb. of solids in suspension and 7-7.5 lb. of solids in solution.

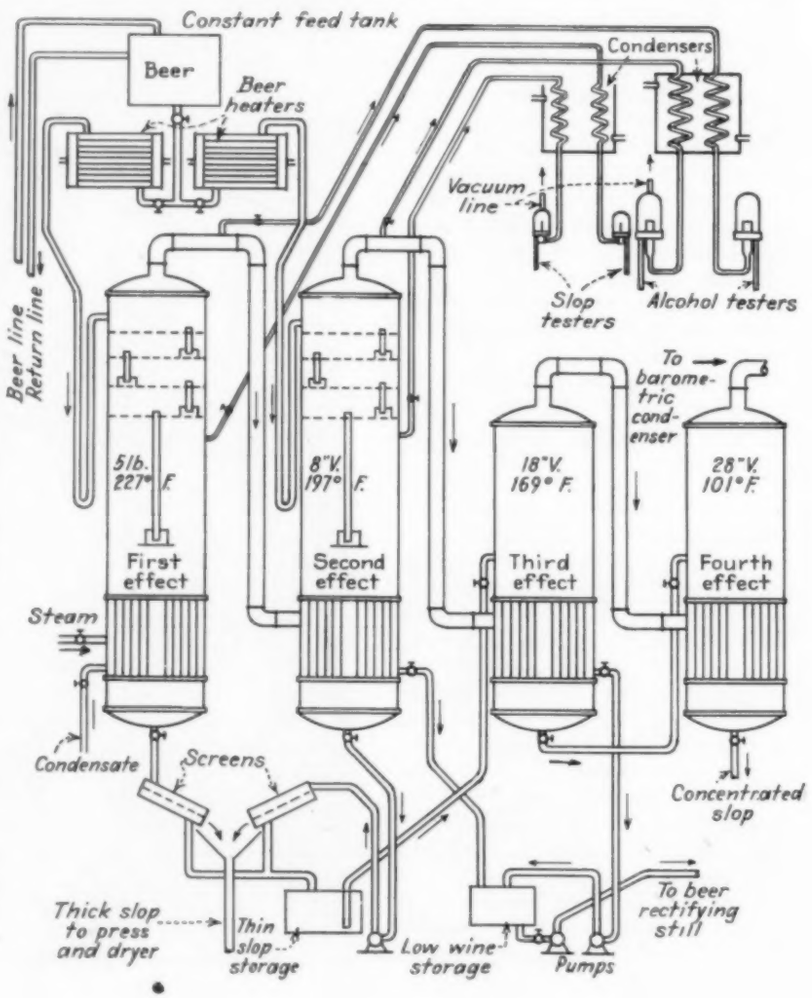
The alcoholic vapors on the top of the beer still are refluxed and at a proof of 100-140 deg. pass into the aldehyde column. In this intermediate column the chief aim is to remove most of the low boiling acetaldehyde; then the alcohol flows to the rectifying column, where the remainder of the acetaldehyde is removed at the top of the column and returned to the aldehyde column. Fusel oil and water are separated from the alcohol in this column also and the proof of the alcohol is raised to 190 deg. Space precludes a discussion of the construction and operation of the aldehyde and rectifying columns.

The usual procedure for the disposal of slop is to separate the suspended solids by screening and concentrating the clear liquor in a triple or quadruple effect evaporator to a density of 25 deg. Brix and then to concentrate in a single effect finishing pan to 50 deg. Brix.

The present article shows other possibilities for the recovery of values from the beer whereby not only the cost of manufacturing the alcohol can be reduced but a considerable increase in the production of alcohol will be possible with a fraction of the investment usually required.

Fig. 3 shows a schematic chart for the simultaneous evaporation of slop and distillation of alcohol. It will be desirable to grind the grain as fine as possible, which will not only increase the yield, but permit easier processing in the evaporator. In *Chem. & Met.*, Vol. 44, No. 3 (1937), the use of a calandria type of evaporator is described. Various combinations have been patented[1] by the author and several patents are pending for a more economical recovery of values from the beer. In Fig. 3 the first and second effects are shown in combination with a short stripping column, joined to the evaporator, which partly serves to degasify the beer and allows

Fig. 3. Process for simultaneous slop evaporation and alcohol distillation



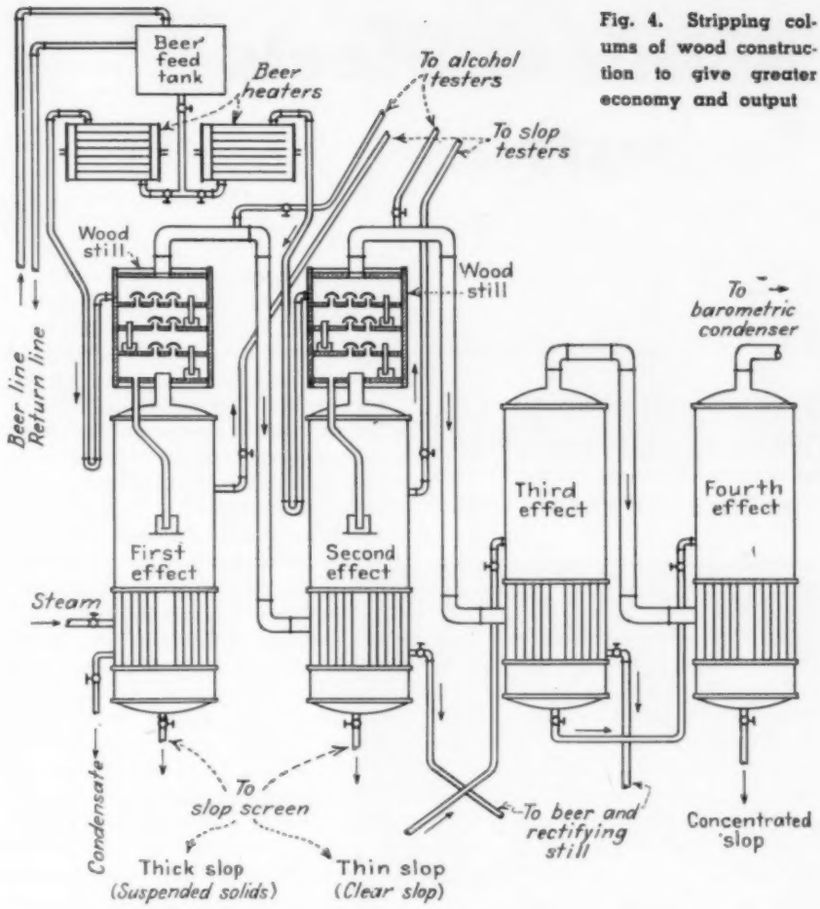


Fig. 4. Stripping columns of wood construction to give greater economy and output

the complete removal of the alcohol. If the distillery does not desire an increased production of alcohol, but merely greater economies, a small stripping column can be attached in the vapor line, between the first and second effects while the slop screen is placed in the liquor line between the first and second effects. Owing to the scarcity of copper and steel the stripping column could be of wooden construction attached to existing effects as shown in Fig. 4 and in which the plates are also made of wood while the bubble caps could be of copper or cast iron. Cypress, oak or redwood are suitable woods for the still.

According to this system a beer still could be omitted as the alcohol condensed in the second effect calandria has a density of 50 deg. proof and is free of all solid matter.

Should an increase in production of alcohol be contemplated, a second stripping column can be placed in the vapor line between the second and third effects. The second effect is to be operated under 8 in. of vacuum and the alcoholic vapors are condensed in the calandria of the third effect. The combined alcoholic condensates of 50 deg. proof "low wine" from the second and third effect calandrias are conveyed to the reconstructed beer still. In one installation of this kind the vapor space between the perforated plates has been filled with packing, such as Berl saddles or Raschig rings. The vapors from the beer still are rectified in the aldehyde and rectifying columns.

The continuous distillation and separation of various fractions in the beer still filled with packing is not quite as convenient as when distilling plates with bubble caps are used. This defect can be largely overcome by substituting a few perforated plates with bubble cap plates. No arbitrary rule can be laid down for the reconstruction of the beer still as each still needs special study, depending upon its function in combination with the rectifying unit.

For the disposal of the slop in connection with the simultaneous evaporation of slop and distillation of alcohol various combinations are possible. It is assumed that either one or two multiple effect evaporators are available, such as triple or quadruple effect evaporators with a finishing pan. The various combinations possible for this type of operation are as follows:

1. Recovery of all the alcohol in the first effect as low wine, raising its proof in the rectifying column, and removal of the suspended solids from the partially concentrated slop before it is transferred to the second effect and finally finishing the concentration in the succeeding effects.

2. Simultaneous evaporation and distillation in a multiple effect evaporator, removal of the suspended solids from the slop between the first and second effects. Recovery of the alcohol at about 50 deg. proof in the first effect and afterwards raising the proof of alcohol in a wooden still to 140 deg. and finally rectifying in a reconstructed beer still as previously described, in combination with the aldehyde column which could be superimposed over the beer still, the rectifying column serving for the final rectification.

3. De-alcoholizing in the first and second effects by feeding half of the beer to the first effect and half to the second effect. In both effects an alcohol of approximately 50 deg. proof is obtained. The suspended solids in the slop from the first and second effects are removed at atmospheric pressure and the "thin slop" from both effects either combined and further concentrated in the succeeding effects or part of the slop may be concentrated and the remainder either run into the river or sewer or treated chemically.

4. It might be advisable to remove all the alcohol and suspended solids in the first and second effects as described under 2; then concentrate all the slop as far as possible in the succeeding effects. Afterwards pass this partially concentrated slop to another multiple effect evaporator in which the first effect serves as a finishing pan, as described by Weber and Robinson in "Evaporation."

In the choice of simultaneous evaporation and distillation, several other variations are possible depending upon the design of the evaporators and also upon the size of their heating surfaces. For simplification purposes essential accessories and piping between evaporator and still have been omitted on the drawings.

In this brief article the aim has been merely to focus the attention of the alcohol distillers on the fact that there are possibilities of overcoming some of their difficulties when they are confronted with a demand for increased production and restricted use of equipment.

[1] U. S. Patents: 1,599,185; 1,930,861; 2,010,929; 2,126,974; 2,127,138; 2,148,579.

Austenitic Stainless Steels In Process Industries

GEORGE A. SANDS Electro Metallurgical Co., New York, N. Y.

Chem. & Met. INTERPRETATION

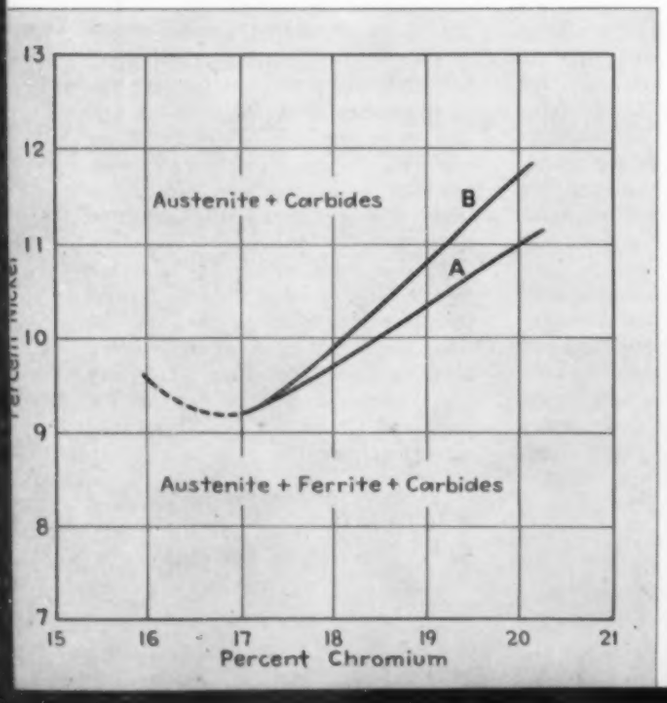
Chemical engineers will find in this article a solution to many fabrication problems involved in the construction of process equipment from austenitic stainless steels. The function of alloying elements and effect of structure in processing the materials are clarified—*Editors.*

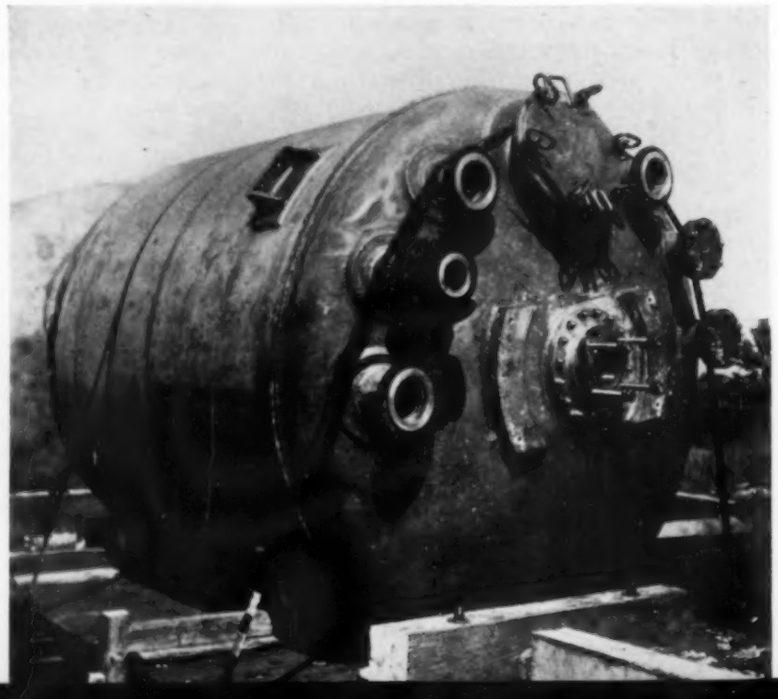
IN THE APRIL ISSUE of this publication (pages 88-91) an article entitled Stainless Steel Development in the Process Industries discussed selection of stainless steels for chemical process equipment and traced the metallurgical developments that have facilitated the construction of process equipment fabricated from straight chromium steel. This second article will deal with the austenitic chromium-nickel and chromium-manganese stainless steels.

As nickel is added to low-carbon straight chromium alloys containing about 18 percent chromium, the structure changes from a single ferritic phase to a duplex phase, ferrite plus austenite, and finally to a single austenitic phase. The minimum amount of nickel added to low-carbon 18 percent chromium alloy to obtain a fully austenitic structure is approximately 8 percent. By maintaining this chromium-nickel ratio, the austenitic chromium-nickel steels commonly known as 18-8, 25-12 and 25-20 were developed. The principal effect of the nickel addition aside from the formation of austenite is to increase ductility, toughness, creep resistance, and resistance to the reducing type of corrosion. These alloys properly balanced are non-magnetic and cannot be hardened by heat treatment. They may be hardened by cold work to give tensile strengths of over 200,000 lb. per sq. in. with adequate ductility for engineering purposes. The annealed steels of this group have exceptionally good resistance to oxidation and creep at high temperature. This combined with excellent working properties and resistance to corrosion under both oxidizing and reducing conditions make them ideal alloys for combating the problems of the process industry. Where ductility is of prime importance, they are often substituted for the straight chromium alloys for handling strong oxidizing agents such as nitric acid or related products. A typical illustration of this point is the use of chromium-nickel wringer baskets to separate mixed nitric and sulphuric acid from nitrocotton.

Addition of manganese to the low-carbon straight 18 percent chromium alloy in amounts from 8-10 percent changes the structure from a single ferritic phase to a duplex structure (austenite and ferrite) which gives us another important alloy belonging to this group. The properties of this alloy are similar to those of the regular 18 percent chromium, 8 percent nickel steel, but it is not quite as resistant to strongly oxidizing media. The chromium-manganese steel does have superior resistance to certain

Left—Structural diagram for chromium-nickel steels containing a maximum of 0.08 percent carbon and Cb = 10xC. Curve A is for steels air cooled from 1,050 deg. C.; Curve B is for steels air cooled from 1,050 deg. C., held for 6 hr. at 650 deg. C. and air cooled. Right—Acetylation autoclave 8x12 ft. fabricated of ½-in. molybdenum-bearing chromium-nickel austenitic stainless steel





reducing conditions involving sulphurous acid and sulphide gases. This alloy has been further modified by the substitution of nickel and copper for part of the manganese to give a single phase austenitic alloy with chemical and physical properties similar to the regular 18-8 chromium-nickel steels. These chromium-manganese steels have made little commercial progress since their discovery in 1930. However, the shortage of nickel in the last year has created a new interest in these steels.

FABRICATION DEVELOPMENTS

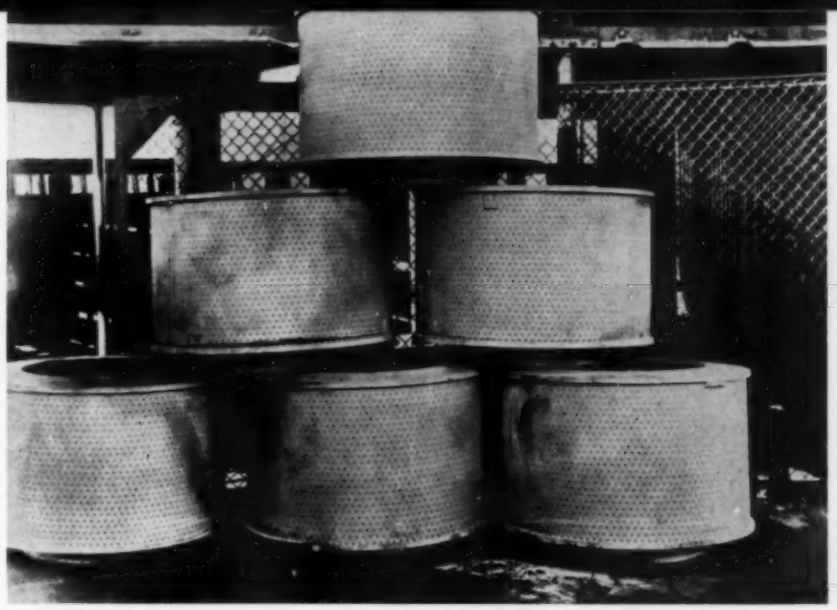
The 18 percent chromium, 8 percent nickel steels were introduced about the same time or shortly after the straight chromium steels. During the early stages of their development the straight chromium steels were favored because they gave better performance under existing fabricating and processing conditions. Eighteen percent chromium, 8 percent nickel steel was among the stainless steels investigated for the first nitric acid plant equipment.

The corrosion resistance of the best quality 18-8 steel was superior to 18 percent chrome steel, but the difficulty of obtaining large plates fully annealed to uniform quality, the detrimental effect of hot and cold forming operations, and the problem of making tight joints of such a highly ductile material by the riveted method of construction gave the straight chromium steels the advantage from the standpoint of constructed equipment. The straight chromium steels were also subject to the detrimental effect of hot and cold forming operations, but this was readily corrected by heat-treatment which was simple to apply in comparison with the drastic quench from 2,000 deg. F. required for austenitic steels. Practically the only maintenance required on properly fabricated straight chromium equipment was due to accelerated corrosion on the cold worked rivet heads and caulked seams, which was finally eliminated by welded construction.

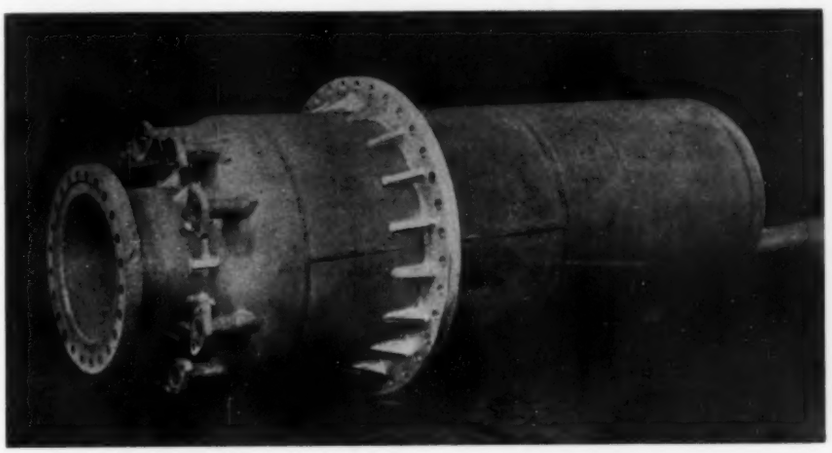
Advantages credited to the straight chromium steels have been completely eliminated by the progress made in the metallurgy of the austenitic steels in the last ten years. Today the application of austenitic steels has far surpassed the straight chromium applications in process industries.

WELDING

The development of welding eliminated the riveted joint problem and



Stainless steel wringer baskets for separating nitrocotton from mixed sulphuric and nitric acids



Autoclave fabricated of low-carbon 18-8 stainless steel. Built for service at hydrostatic pressures up to 1,000 lb. per sq. in.

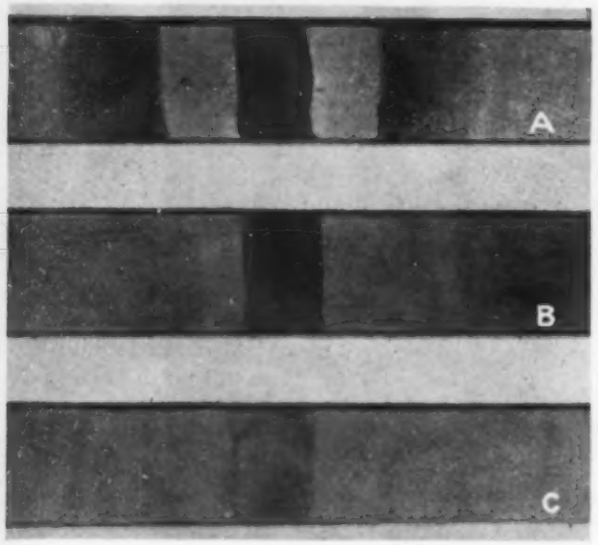
was the first progressive step in stimulating the use of the chromium-nickel steels. These steels are so tough and ductile that the weld deposit ductility has never been a problem. Therefore, the development of welding technique to produce sound welds was much simpler than in the case of straight chromium steels. The major problem, as in the case of straight chromium steel, was the production of corrosion-resistant welds. Like the welding of the straight chromium steels, the most important contribution to successful welding of austenitic stainless steels was the use of special coated rods and application of heat-treatment subsequent to welding. This treatment consisted of quenching from temperatures of 1,900-2,000 deg. F.

TYPICAL FAILURES

The first welded installations of stainless steel were not heat-treated subsequent to welding and as a result began to fail due to intergranular corrosion both in the area adjacent to the weld, and in areas exposed to temperatures of 800 to 1,600 deg. F. during fabrication; also some failures were traced to faulty processing of the material. During the early development of these steels, it was not uncommon to get austenitic stainless steel of poor quality which was usually the result of faulty heat-treatment. Manufacturing technique has improved to the extent that the possibility of obtaining poor quality stainless steel from the leading producers is remote.

HEAT-TREATMENT

All straight chromium-nickel austenitic stainless steels, which do not contain columbium or titanium, when subjected to the temperature zone of 800 to 1,600 deg. F. are susceptible to intergranular corrosion and physical impairment which is caused by carbide precipitation at the grain boundaries. A re-solution of these carbides and restoration of corrosion re-



Weld specimens showing effect of columbium in 18-8 steel welds as tested in hot nitric-hydrofluoric acid. A—Plain 18-8 as welded; B—Plain 18-8 full annealed; C—Columbium-bearing weld metal and plate (as welded)

sistance and physical properties is accomplished by heat-treating at a temperature between 1,900-2,000 deg. F. followed by quenching in air, water, or water spray, the quenching medium depending upon the size and thickness of the metal or equipment. Since it is impossible to fabricate equipment without exposing the metal to this temperature range, methods were devised for heat-treating all welded equipment used for corrosive service. This heat-treatment, together with the development of the .08 percent maximum carbon alloys, met with considerable success but was far from satisfactory, due to the following limitations:

1. The adequacy of the quenching method was always questionable because of the human element and the frequent lack of quenching facilities.

2. Size of equipment was limited by the capacity of commercial heat-treating furnaces.

3. The wall thickness or total metal cross-section of equipment was limited to those thicknesses that could be quenched rapidly enough to prevent carbide precipitation.

Even though conditions were favorable for producing equipment heat-treated perfectly, the fabricator was still confronted with the problem of stress-relieving pressure vessels. In order to assure the maximum safety for pressure vessels, the A.S.M.E. Boiler Code requires that stresses set up in welding or forming Class I U-68 vessels shall be relieved by heating uniformly to a suitable stress-relieving temperature and held at that temperature for a time at least equivalent to one hour per inch of maximum thickness, followed by slow cooling in air. Indications are that a suitable stress-relieving temperature for austenitic stainless steel would be in the range of 1,000 to 1,650 deg. F. Slow cooling from these temperatures would destroy the valuable corrosion resistance and physical properties of these steels. Also, the consumer was greatly handicapped in the plant maintenance of equipment because the heat from field welding would destroy the corrosion resistance of localized areas of the equipment. Add these limitations to the problem of combating corrosion at temperatures above 800 deg. F. and you will have some idea of the situation that existed prior to the modification of the austenitic stainless steels with the elements titanium and columbium.

Cb—Ti AUSTENITIC CHROMIUM NICKEL STEELS

After considerable research, metallurgists have overcome all the difficulties enumerated, by stabilizing the low-carbon austenitic chromium-nickel steels with the addition of less than 1 percent columbium or titanium. This development has made the austenitic steels foolproof in respect to the effect of heat, and has made fabricated stainless steel pressure vessels as readily available as vessels of ordinary carbon steel. This development led the Boiler Code Committee of the A.S.M.E. to adopt code regulations Case 897 covering U 68 Class I pressure vessels constructed of stainless steel.

The stabilizing elements columbium and titanium have a greater affinity for carbon than do chromium and iron and thereby form a stable, harmless carbide which is scattered through the austenitic matrix. The amount of these elements necessary for stabilization of the alloy depends on the fabrication treatment and service; a columbium-carbon ratio of 10 to 1, or a titanium-carbon ratio of 5 to 1, are the minimum ratios required for stabilization of these steels under the most severe temperature conditions.

To obtain the maximum benefits to both the user and manufacturer, the stabilized stainless steel should be well balanced to form a fully austenitic structure. During the early part of this development, the effect on structure due to the addition of small amounts of strong ferrite-forming elements, such as columbium and titanium which are also strong carbide-forming elements, was not fully appreciated and thus unbalanced alloys were produced which caused manufacturing as well as fabrication difficulties. If the alloy is out of balance, a duplex structure is formed, containing austenite with a small amount of ferrite. The presence of a small amount of ferrite may make the alloy susceptible to general corrosion in the ferritic phase after subjecting to long periods in the dangerous temperature zone (800 to 1,600 deg. F.), and has an adverse effect on the hot-working and welding properties. In other words, the additional ferrite-forming elements columbium or titanium should be compensated for by the addition of austenite-forming elements, such as nickel or manganese, to keep the structure fully austenitic. It has been found in the fabrication of these steels that from 1 to 2 percent manganese is of special value in improving the hot-working, forming, and welding operations.

Because titanium oxidizes so readily at high temperatures, columbium-bearing rods should be used in welding. The welding rods should be of such a composition that the deposited metal will conform to the composition of base metal. Allowance must be made for slight losses of the oxidizable elements in the rod. In addition to the required amount of columbium (8 to 10 times the carbon content in the deposit metal), about 2 percent manganese and 0.70 percent silicon are recommended in the rod composition, and the chromium content should be about 1 percent higher than that of the base metal. The manganese produces cleaner, sounder, and more ductile welds and the silicon, which is about 0.25 percent more than normally used, gives better recoveries of columbium in weld metal.

Among the many new applications that have been made more feasible by the development of the stabilized composition is the use of austenitic stainless steel for all-welded tank car construction. A tank car is not strictly a pressure vessel, but because of the hazards involved in railroad transportation, it is advisable to specify its construction in accordance with the A.S.M.E. Boiler Code U-68 for pressure vessels.

The detrimental effect of cold work on the corosion-resistant properties of the austenitic stainless steels is an important factor in the manufacture and fabrication of these steels. Some practical experience indicates that the austenitic stainless steels containing columbium are not as sensitive to the detrimental effects of cold

working as the austenitic steels which do not contain a stabilizing element. However, the only certain method of eliminating the effect of cold work is to quench the metal from the solution temperature of 1,800 to 2,000 deg. F.

AUSTENITIC STEELS CONTAINING Mo

The addition of molybdenum to the austenitic chromium-nickel steels in amounts from 2 to 4 percent was found to increase greatly the resistance of these steels to the reducing and pitting types of corrosion. These steels are subject to all the fabricating problems described for regular chromium-nickel steels that do not contain a stabilizing element. Also, due to the fact that molybdenum is a strong ferrite and carbide-forming element, care must be taken to balance the alloy with austenite-forming elements in order that it may be successfully hot-worked. The austenitic chromium-nickel-molybdenum steels, or fabricatel equipment which are subjected to the heat of welding and forming operations, must be in the fully annealed condition (quench from 2,000 deg. F.) in order to maintain their maximum corrosion resistance.

AUITENITIC STEELS CONTAINING Mo AND Co

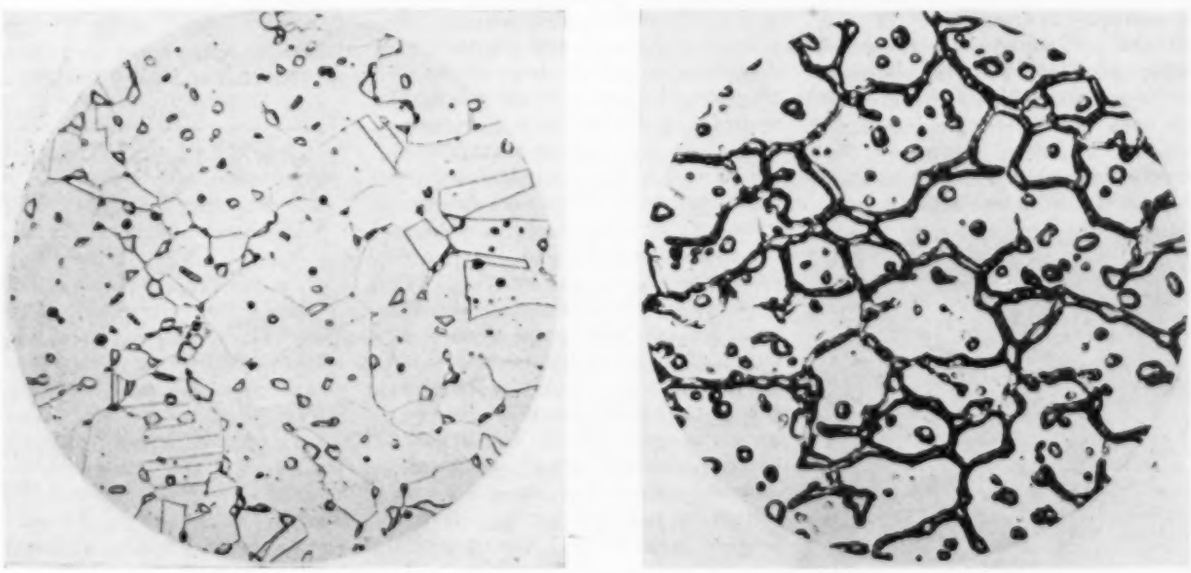
Because of the urgent demand of the process industries for an alloy of the chromium - nickel - molybdenum type, which would remain unaffected by service temperatures and meet the requirements of fabrication without the necessity of final heat-treatment, laboratories of Electro Metallurgical Co. investigated the possibilities of stabilizing this alloy with columbium. The results of this investigation proved that the chromium-nickel molybdenum alloys could be stabilized in the same manner as the chromium-nickel alloys without molybdenum, but because of the double addition of strong ferrite and carbide-forming elements, molybdenum and columbium, the balancing of this composition so as to retain a completely austenitic structure at room temperature became more critical. The reason for placing so much emphasis on the balance of the alloy is because only single-phase austenitic alloys can be completely stabilized.

If the alloy is made up of two phases, consisting of a primary austenite phase and a secondary ferrite phase, the addition of columbium will completely stabilize the austenite, but the secondary ferrite phase undergoes a transformation when subjected to temperatures between 800 and 1,600 deg. F. to a structure which is sometimes referred to as sigma phase. The presence of this sigma phase makes the alloy susceptible to general corrosion, not intergranular, and lowers the impact value of these steels. The ferrite transformation will occur at temperatures between 800 and 1,600 deg. F. in any of the unbalanced austenitic steels and should not be attributed to the presence of any specific element in the alloy. This phenomena is a function of both structure and composition.

After considerable research, the laboratories of the Electro Metallurgical Co. succeeded in properly balancing the ferrite and austenite-forming elements of this composition so that it may be used satisfactorily for equipment both in the as-welded and stress-relieved conditions for chemical equipment in continuous service below approximately 1,000 deg. F.

In an attempt to balance the austenitic chromium-nickel steels containing columbium and molybdenum, it was found that the most effective molybdenum content was approximately 2 percent. Since molybdenum was the most effective element introduced for combating the pitting type of corrosion, and in order to substantiate the laboratory data, this company has been conducting a cooperative testing program for the past two years with several of the larger units of the process industries to determine the most effective molybdenum content. Chromium-nickel alloys containing 2 percent molybdenum and 3 percent molybdenum, with and without columbium, are being tested in various plant processes under highly reducing conditions. This work is nearly completed and the preliminary results indicate that the corrosion resistance of the alloys containing 2 percent molybdenum is as good or better than the corrosion resistance of the alloys containing 3 percent molybdenum. The carbon content of these steels was .08 percent maximum, and the columbium 7 to 10 times the carbon content.

Photomicrographs showing the etched structure of a steel containing 18.30 percent chromium, 9.58 percent nickel, 0.46 percent manganese, 0.47 percent silicon, 3.26 percent molybdenum, 0.06 carbon. Magnification, 500X. Left—Heated 10 min. at 2,010 deg. F. and air cooled. Structure of the steel after this treatment consists of austenite and ferrite. Right —Heated 10 min. at 2,010 deg. F. and air cooled, reheated 4 hr. at 1,600 deg. F. and air cooled. Practically all ferrite is converted to sigma by this treatment



Avoiding Formation of Hydrocarbon Hydrates

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Chem. & Met. INTERPRETATION

For the past several years, there has been considerable interest throughout the natural gas and natural gasoline industries in the subject of the formation of solid substances by the inter-action of water and hydrocarbon gases. These solids are commonly referred to as "hydrates". Herein the author discusses factors causing hydrates and means for preventing their formation.—*Editors*

WHEN TRANSMISSION systems and plant equipment were operated at low pressures, the occurrence of hydrates in the field was less frequent than under present conditions when relatively high pressures are commonly used. During the period when only low pressure systems were operated, it was usually necessary that low temperatures be reached before hydrates would form and become stable. As pressures increased, it was found that solids appeared at temperatures considerably above 32 deg. F.; in fact, it is quite possible to have natural gas hydrates at temperatures in the neighborhood of 50 deg. F. with pressures of about 500 lb. per sq.in.

Although there is considerable doubt as to the exact composition of many hydrates of normally gaseous substances, we may assume that all hydrocarbon hydrates contain six molecules of water. Hydrates of ethane, propane, and the butanes have been reported in the literature and data have been published to show the conditions necessary for their formation. There is considerable doubt as to whether normal butane forms any hydrates; Hammerschmidt could not produce this hydrate at pressures up to 800 lb. per sq.in. To date, it is definitely true that no hydrates of hydrocarbons heavier than butane have been reported.

Table I—Analyses of Natural Gases [1]

Compound	Mole Fractions		
	Gas B	Gas C	Gas D
Nitrogen	0.0064	0.0043	.....
CO_2	.....	0.0051	.....
Methane	0.8641	0.9320	0.8836[2]
Ethane	0.0647	0.0425	0.0682
Propane	0.0357	0.0161	0.0254
Isobutane	0.0099	.....	0.0038
n-Butane	0.0114	.....	0.0089
Pentanes +	0.0078	.....	0.0101

[1] Data by Wilcox, Carson and Katz.
[2] Includes nitrogen.

It will be seen from Fig. 1 that conditions required for hydrate formation will vary, depending upon the gas. These curves represent equilibrium conditions for the co-existence of the solid hydrates, the vapor phase and liquid water for the three pure gases, methane, ethane and propane. At any point along the curve the hydrates may exist in equilibrium with the other two phases. However, if temperature and pressure conditions are such as to be above the curve, only vapor and liquid water may exist; while if they are such as to be below the curve, vapor and hydrate will exist. At a given temperature methane requires a much higher pressure for the production of a hydrate than ethane or propane. In fact, propane will form hydrates very readily at temperatures well above the freezing point and at pressures in the neighborhood of 50 lb. per sq.in. This indicates that hydrates are more readily formed as the molecular weight of the hydrocarbon increases.

Data for isobutane are not definite enough to establish the position of its curve. When these gases are present in mixtures, of course, the position of the equilibrium curve depends upon the composition. Fig. 2 shows curves for three natural gases having different compositions, especially with respect to propane content. It will be seen from Table 1 that gas "B" is a relatively wet gas, while gas "C" has very little propane present, and the fractions heavier than propane are absent. Gas "D" is of intermediate composition. Referring again to the equilibrium curve, we find that their positions are consistent with the analyses previously mentioned. Gas "B" will most readily form a hydrate; that is to say, at a given pressure it will form a hydrate at a higher temperature than the other two gases, or at a given temperature it will form the solid at a lower pressure than is possible with the others. Gas "B" has the lowest methane content and highest ethane and propane content of the three gases.

The primary conditions which must be fixed in order that hydrates will be formed are temperature, pressure, and composition. The composition of the gas determines the position of the equilibrium curve with respect to pressure and temperature. In connection with composition, it is always necessary that the gas be saturated with respect to water vapor at the equilibrium point before hydrate crystals will appear.

HYDRATE FORMATION

Although primary conditions may be proper for hydrate formation, it is not always true that the solid will immediately appear. These gas-water mixtures have a tendency to exist for long periods of time under metastable conditions. Certain secondary effects play a large part in determining whether solids will appear. For example, high velocities, turbulence, pulsations from compressors, sharp bends, and similar conditions which readily promote a mixing action will augment the for-

Table II—Temperatures and Pressures for Formation of Natural Gas Hydrates [1]

Gas B		Gas C		Gas D	
Temp., °F.	Pressure, lb./sq. in. abs.	Temp., °F.	Pressure, lb./sq. in. abs.	Temp., °F.	Pressure, lb./sq. in. abs.
		1st Series		1st Series	
42.2	182	40.2	222	38.5	175
49.5	279	51.3	492	47.2	317
60.0	598	60.8	1010	53.2	510
66.2	1010	66.0	1523	60.0	790
69.6	1404	68.3	2049	64.5	1190
71.5	1779	....	....	68.1	1740
73.3	2443				
75.0	3000	2nd Series		2nd Series	
77.3	3963	42.7	279	60.8	895
		47.6	384	66.0	1350
		56.4	699	69.4	2040
		62.8	1180	71.3	2640
		64.5	1375	74.7	3850
		68.3	1999	73.0	3270
		71.3	2939		
		70.0	2489		
		74.3	3989		
		72.3	3335		

[1] Data by Wilcox, Carson and Katz.

mation of the solid base. On the other hand, conditions which result in low velocity and little turbulence may allow gases to exist without the formation of a solid base even though the three primary conditions may be in proper relationship. Once the solid has started to form, it will proceed very rapidly under proper conditions because of the "seeding" effect of the crystals which have developed.

Consideration might be given to a typical example such as might be found in a pipeline. If the gas flowing in this line is of the composition of gas "B" and has a water content such that it would be at a dew point with respect to water at any temperature and pressure along the equilibrium curve for this gas, we would find that hydrates could form whenever such conditions would exist. For example, if this gas is maintained at a pressure of 300 lb. per sq.in., hydrates would start forming at a temperature of 50 deg. F. At higher pressures, near 1,000 lb. per sq.in., hydrates might be formed at a temperature in the neighborhood of 66 deg. F. Of course, it is to be assumed that conditions are such as to allow the heat of formation of the hydrates to be conducted away from the pipeline and be removed from the system. If the transmission line contains liquid water as well as water vapor, it is possible to form a much larger quantity of hydrates than might be the case if the water were only in the vapor phase.

METHODS OF CONTROL

Hydrate control can be divided into two categories. First is the problem of eliminating hydrates which may have already formed and which must be removed in order to restore the equipment into proper operating condition. Such situations usually arise because gas is handled at high pressures and relatively low temperatures without preliminary hydration. From the curves of Fig. 2 it is obvious that one simple method for removal of hydrates is to lower the pressure in the system so that it is below the equilibrium point. The hydrate will then be decomposed into hydrocarbon gas and water.

However, this is not always possible since frequently it is necessary to maintain pressure above the equilibrium point for other reasons. Furthermore, it is sometimes possible to lower the pressure to accommodate a given temperature condition at one point and find that the temperature is low enough at another point in the system so that the new pressure is sufficient to produce hydrates at that point.

Another expedient would be to raise the temperature at the point where hydrates exist. This has been attempted in some instances by building fires around lines to raise the temperature to the point where hydrates can no longer exist. This is unsatisfactory because the entire system can never be raised sufficiently to temperatures to preclude the reformation of hydrates at another point. Furthermore, this practice is dangerous. Removal of liquid water from equipment does not obviate the possibility of hydrate formation since gas which is saturated with water vapor can deposit hydrates in at least small amounts under proper temperature and pressure conditions. Removal of the liquid water can merely reduce the total amount of hydrates which might be formed.

When equipment has become plugged by accumulations of hydrates, it is possible to cause their decomposition by the introduction of substances which have a lowering effect upon the composition temperature. For example, methyl, ethyl or propyl alcohol may be added in very small amounts to the gas line and the solid hydrates will decompose. It has also been demonstrated that gaseous ammonia will serve the same purpose. However, the use of ammonia gas under conditions where carbon dioxide is present may result in situations which are even worse than the development of hydrates. Ammonia can form solid ammonium carbonate with any CO_2 which is present and this will accumulate at points to form a plug which is not readily removed. It is not possible to decompose this compound by depressuring or increasing temperature in a manner similar to that which may be used with hydrates.

So far we have discussed only methods alleviating a condition where hydrates already exist. It is of more importance to arrange a gas transmission system so that hydrates cannot be formed under any conditions. In order to accomplish this, it is necessary to dehydrate the gas so that it will never become saturated with water vapor under any temperature and pressure which it may encounter in the system. It is not necessary that all water be removed from the gas so long as the amount remaining is insufficient to bring the gas to its dew point with respect to water at the lowest temperature.

Methods of dehydration may include such processes as dew point

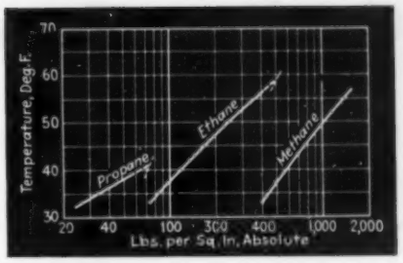


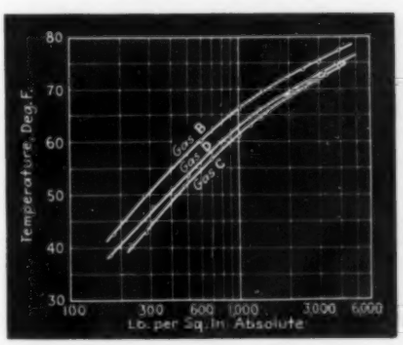
Fig. 1—Hydrate decomposition curves for pure gases

lowering by refrigeration; water removal by absorption in glycol dehydration plants; water removal by contact with solid dehydrating agents such as activated alumina or silica gel; dew point lowering by contacting the gas with calcium chloride or sodium chloride brine. It is also possible to take advantage of the decomposition temperature lowering effect of the chemical agents mentioned above by adding them to the gas flowing in the equipment before hydrates are formed.

It is now general practice to preclude the possibility of forming hydrates by using dehydration methods, and these should always be included in systems where hydrate formation is anticipated. It is obvious that the method of dehydration will depend upon local conditions. Pressure throughout the installation will be a determining factor in selecting the proper process for maintaining a sufficiently low dew point with respect to water.

It is to be expected that as higher pressures are utilized in plant operations and field installations, such as are now being encountered in repressuring and recycling systems, the problem of hydrate formation will become more troublesome. This is to be expected because at pressures in the neighborhood of 2000-3000 lb. per sq.in., the equilibrium temperature may easily be as high as 70 deg. F.

Fig. 2—Conditions for formation of natural gas hydrates



Cooling Tower Psychrometry—II

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Chem. & Met. INTERPRETATION

Principles of psychrometry were reviewed last month in the first of a series of articles on water cooling tower fundamentals. This article is concerned with the humidity chart and advances a new concept: the "psychrometric polygon." The next and concluding installment will concern heat exchange in forced convection towers.—*Editors.*

IF THE humidities of saturated air are plotted as vertical ordinates against their corresponding air temperatures as abscissas, the plotted points will lie on the saturation curve for the atmospheric mixture of air and water. Such a curve has been plotted in the humidity chart, Fig. 3. When the air is saturated, the dry-bulb temperature equals both the wet-bulb temperature and the dew-point temperature. When the air is not saturated, however, the wet-bulb temperature lies between the dew-point temperature and the dry-bulb temperature. If make-up water at a constant temperature equal to the wet-bulb temperature of unsaturated air is allowed to evaporate into the unsaturated air, the humidity of the air will increase and the dry-bulb temperature of the air will decrease until the rising dew-point temperature equals the falling dry-bulb temperature at the temperature of the make-up water. The point on the humidity chart located at the humidity of the unsaturated dry-bulb temperature is the starting point of the path line for humidification and cooling of the air. This path line is drawn as a straight line with a slope determined from the humid specific heat of the air at the start of humidification and the latent heat of water vapor at the temperature of the make-up water.[30]

The constant wet-bulb lines of the humidity chart of Fig. 3 are paths drawn as straight lines from the point of initial humidity and dry bulb of the unsaturated air to the intersection of the saturation curve and the ordinate which passes through the temperature of the wet bulb. The humidity chart of Fig. 3 is the basic field upon which the familiar psychrometric chart is plotted. It should be borne in mind, however, that the path lines of the humidity chart are straight lines only when the temperature of the make-up water remains constantly at the wet-bulb temperature of the air.

The humidity chart is designed for the conditions of a fixed barometric pressure; this pressure is designated by the symbol B. When the barometric pressure differs from the pressure B, adjustments must be applied to the basic chart. The application of the adjustments may be made as follows:

Eq. (7) is written for the case in which the barometric pressure is B. If the barometric pressure is B_s, and if the partial pressure of water vapor in the air is p_s, the forms of Eq. (7) for B and B_s are, respectively,

$$p_a = p_w - (B - p_w)(t - t_w)/e \quad (28).$$
$$p_s = p_w - (B_s - p_w)(t - t_w)/e \quad (29).$$

In these equations, $e = 2{,}800 - 1.3t_w$.

Let $p_s - p_a$ equal Δp, and let H (the humidity at t, t_w, and B) be defined by Eq. (6) as $H = 0.6220p_a/(B - p_a)$. H_s is defined as the humidity which would be present at barometric pressure B if the partial pressure of the water vapor were that which would be present under the psychrometric conditions of B_s, t, and t_w. H_s is *not* the humidity at B_s, t, and t_w. Therefore,

$$H_s = 0.6220\,(p_a + \Delta p)/(B - p_a - \Delta p) \quad (30).$$

If $(B - p_a - \Delta p)$ is assumed equal to $(B - p_a)$,

$$H_s - H = 0.6220\,\Delta p/(B - p_a) \quad (31).$$

Eq. (29) minus Eq. (28) gives

$$\Delta p = (t - t_w)(B - B_s)/e \quad (32).$$

The value of Δp obtained from Eq. (31) is set equal to the value of Δp obtained from Eq. (32) and the resulting equation is

$$(H_s - H)(B - p_a)/0.6220 = (t - t_w)(B - B_s)/e \quad (33).$$

or,

$$H_s - H = (0.6220\,(B - B_s)(t - t_w)/e\,(B - p_a) \quad (34).$$

However, the equation of the constant line of adiabatic saturation is [20]

$$(H_w - H)/(t_w - t) = -(0.24 + 0.45H)/r_w = -s/r_w \quad (35),$$

where s is the humid specific heat at temperature t. Eq. (33) combines with Eq. (35), using $(t - t_w)$ as a basis for equality:

$$(t - t_w) = (H_w - H)\,r_w/s = (H_s - H)(B - p_a)e/0.6220\,(B - B_s) \quad (36).$$

If an average value of t_w is set at 77 deg. F., r_w equals 1,051 B.t.u. per lb. Furthermore, the value of e is then 2,700. These values of r_w and e are substituted in Eq. (36) to yield

$$1{,}051\,(H_w - H)/s = 2{,}700\,(H_s - H)(B - p_a)/0.6220\,(B - B_s) \quad (37).$$

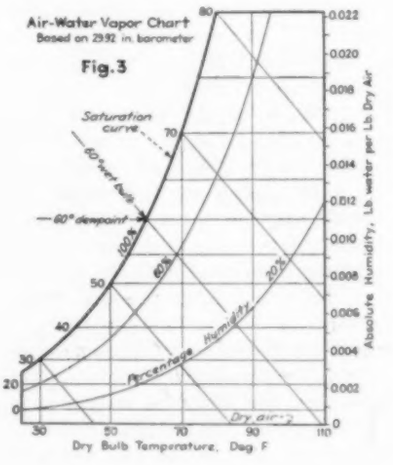
Let $(H_s - H)/(H_w) = f$. Then, through the use of Eq. (37), the value of f may be defined as

$$f = (0.6220)(1{,}051)(B - B_s)/2{,}700s\,(B - p_a) = (B - B_s)/4.13s\,(B - p_a) \quad (38).$$

The lowest value of s for dry air would be 0.24 B.t.u. per lb. per degree F. Where the basic humidity chart value of B is 30 in. Hg, $1/4.13s$ $(B - p_a)$ is replaced by $1.02/B$, where the numerical value 1.02 is an adjusted constant. With the humidity chart based upon $B = 30$ in.

$$f = 1.02\,(30.0 - B_s)/30 = (30.0 - B_s)/29.4 \quad (39).$$

The value of H for the air conditions at a barometer of 30 in. is corrected to a plotting value H_s by the addition of an adjusted humidity difference. The value of f which is



equal to $(H_s—H)/(H_w—H)$ is substituted in Eq. (39), and the final equation is

$$H_s = H + [(30.0 - B_s)(H_w - H)]/29.4 \qquad (40).$$

The actual humidity at the problem conditions of air temperature and barometric pressure is closely evaluated by the utilization of an approximate form of Eq. (6). Inspection of that equation will indicate that the term $(B—p_w)$ is but slightly affected by the quantity p_w. Thus, very little error will be introduced if the ratio of the actual humidity to H_s is assumed equal to the ratio of B to B_s; for, H_s exists at B with a partial pressure of water vapor which would be present under the psychrometric conditions at B_s. Therefore, the humidity for conditions at B_s is

$$H_s = H_s B/B_s \qquad (40a)$$

where H_s is the humidity at the problem conditions of B_s, t, and t_w.

If air which is unsaturated is allowed to contact a *water moistened* surface that is at a temperature which differs from the air temperature, the path of psychrometric change of the air will lie along a straight line.[6,7,8] Thus, if the temperature of the air were 115 deg. F. with a wet-bulb of 70 deg. F., the entering condition would be found at the point where the sloping 70 deg. wet-bulb line intersected the 115 deg. dry-bulb line. If the temperature of the wetted surface in contact with the air were 80 deg. F., the path of the cooling of the air would be along a straight line drawn from the entering condition point to the point for 80 deg. F. located on the saturation line. In a cooling tower, the air and water continuously change temperature throughout the apparatus, and the path line is curved instead of straight. If the total action of air with water is divided into a number of small actions which occur respectively in a number of small sections of the tower, the principal of the straight-line psychrometric path may be used.

If the sizes of the tower sections for the step travel through the tower are based upon equal changes in the temperature of the water, the physical dimensions of the sections will vary, since the driving forces which exist between water and air will constantly change. In each section there will be an average water temperature; the air condition point is joined to the average water temperature of the small water temperature range occurring in the small tower section.

Let ΔT equal the temperature interval of the small temperature range which exists for the typical small heat action of the step-divided tower. Then, for a water temperature of T, the range is from $(T + \Delta T/2)$ to $(T—\Delta T/2)$, and the average temperature is T. The value of the temperature which is one temperature step below the entering water temperature of Fig. 2 is $T_2—\Delta T$. Likewise, the value of the water temperature which is one temperature step above the leaving water temperature is $T_1 + \Delta T$. At the top of the tower, there will be a smaller range interval extending from T_2 to $(T_2—\Delta T/2)$; the magnitude of this smaller range is therefore $\Delta T/2$, and the average temperature over this smaller range is $T_2—\Delta T/4$. At the base of the tower, the average temperature of the smaller terminal range is $T_1 + \Delta T/4$, and the value of the range is $\Delta T/2$. The average temperatures are computed for the subdivided tower, and the heat exchanges are computed for the typical value of ΔT and the lesser value of $\Delta T/2$.

Inspection of Eq. (27) indicates the possibility of the use of an approximate form of the sigma function for design estimating. A new quantity, Σ'_2, is defined:

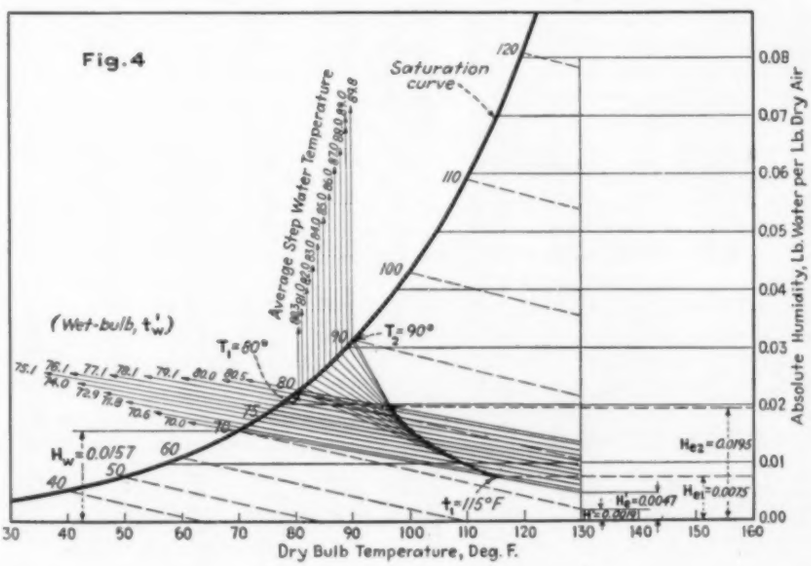
$$\Sigma'_2 = \Sigma_1 + L_2 (T_2 - T_1)/G \qquad (41).$$

The following example will be used to indicate the method of plotting the *psychrometric polygon* for the condition of the air during its passage through the cooling tower: $T_2 = 90$ deg. F.; $T_1 = 80$ deg. F.; $t_{w1} = 70$ deg. F.; $t_1 = 115$ deg. F.; $B_s = 24.0$ in. Hg; and $L_2/G = 1.15$. The value of ΔT is set at 1.00 deg. F. Then $(T_2—\Delta T/4) = 89.75$ deg. F.; and $(T_1 + \Delta T/4) = 80.25$ deg. F. The value of Σ_1, equal to 37.66 B.t.u. per lb. of dry air, is taken from Table II.

The value of the sigma function for the entering wet-bulb of 70 deg. F. is the starting point for the computation of the various values of Σ'. Thus, $37.66 + 0.575 = 38.24$, which is the value of the sigma function corresponding to the wet-bulb of the air leaving the step zone in question. With the values of Σ' thus determined, the values of t'_w are taken from Table II.

The condition of the air is located on the humidity chart, and this location is the starting point for the psychrometric polygon. The actual method of drawing the polygon is as follows: The basic humidity chart is covered with a piece of tracing paper; the wet-bulb lines are drawn at the correct slope for the barometric pressure and the temperature of the entering wet-bulb; all other wet-bulb lines have the same slope and hence are drawn parallel to the line for the initial wet-bulb; after the line has been drawn for the entering wet-bulb temperature, the parallel lines are drawn from the saturation curve, with starting points on the curve located at the various values for t'_w which are listed in Table III. In Fig. 4, which is the chart for the solution of the example, the positions of the wet-bulb lines of the standard barometric chart are shown dashed. The lines which apply at the barometric pressure in question are solid lines. The various lines, which are drawn in at the respective values of t'_w, are identified in the figure. The average temperatures which correspond to the respective values of t'_w are also located on the saturation curve.

The wet-bulb line for the entering air has been oriented from a location on the 130 deg. F. dry-bulb line. At wet-bulb of 70 deg. F., dry-bulb of



130 deg. F., and barometer of 30.0 in., the following values apply: $H_w = 0.0157$ lb. water; $H' = 0.0019$ lb. of water; and, by the conditions of the problem, $B_r = 24.0$ in. These quantities are substituted in Eq. (40) to give $H'_r = 0.0019 + (30.0—24.0)\ (0.0157 —0.0019)/29.4 = 0.0047$ lb. of water. The line is drawn from the 70 deg. F. point on the saturation curve to a humidity of 0.0047 on the vertical dry-bulb line for 130 deg. F.

Next, a line is drawn from the starting point at the condition of the entering air to the average temperature of the first step. This average temperature is 80.3 deg. F. Where the first line thus drawn intersects the line for the wet-bulb t'_w leaving the step, a point is established for directing the next line. The next line is then drawn from this intersection to the average temperature for the next step and the intersection is made with the next wet-bulb line as before. Thus, the first line runs from the starting condition to 80.3 deg. F., and the first intersection is with the wet-bulb line for 70.6 deg. F. The next line runs from this intersection to 81.0 deg. F., and the second intersection is with the wet-bulb line for 71.8 deg. F. This system of line pointing is used until the last and highest wet-bulb line of the problem has been crossed. The last intersection locates a condition of air which is very nearly the true condition of the leaving air. However, since the polygon has been drawn with a terminal wet-bulb corresponding to Σ'_2 instead of the true value of Σ_2, a slight correction should be applied; but the condition of the air as indicated by the terminal end of the polygon is very close to the true terminal condition of the air.

The amount of pickup of moisture by the air is the difference between the humidity of the leaving air and the humidity of the entering air. Thus, with the humidity chart as a basis, the equation for computation of the gain in moisture is:

$$\text{Pickup} = B\,(H_a - H_a)/B. \qquad (42).$$

In the example under consideration, the following values exist: $B_r = 24.00$ in. Hg; wet-bulb = 70 deg. F.; dry-

Table III.

T_{av}, Deg. F.	Range, Deg. F.	$\Delta\Sigma$	Σ'	t'_{w_1} Deg. F.
89.8	0.50	0.575	49.16	80.5
89.0	1.00	1.15	48.59	80.0
88.0	1.00	1.15	47.44	79.1
87.0	1.00	1.15	46.29	78.1
86.0	1.00	1.15	45.14	77.1
85.0	1.00	1.15	43.99	76.1
84.0	1.00	1.15	42.84	75.1
83.0	1.00	1.15	41.69	74.0
82.0	1.00	1.15	40.54	72.9
81.0	1.00	1.15	39.39	71.8
80.3	0.50	0.575	38.24	70.6
80.0	....	.....	37.66	70.0

Table II — Sigma Functions in B.t.u. per Pound Dry Air. Temperatures in Degrees Fahrenheit and Pressures in Inches of Mercury

	BAROMETRIC PRESSURES									
TEMP.	30.00	29.00	28.00	27.00	26.00	25.00	24.00	23.00	22.00	TEMP.
32	11.73	11.87	12.02	12.18	12.35	12.54	12.75	12.97	13.21	32
33	12.14	12.29	12.44	12.61	12.79	12.98	13.19	13.42	13.68	33
34	12.55	12.70	12.86	13.04	13.23	13.43	13.65	13.89	14.16	34
35	12.97	13.13	13.30	13.48	13.67	13.88	14.11	14.36	14.64	35
36	13.39	13.55	13.73	13.92	14.13	14.35	14.59	14.85	15.14	36
37	13.81	14.00	14.17	14.37	14.58	14.82	15.07	15.34	15.64	37
38	14.26	14.44	14.63	14.84	15.06	15.30	15.55	15.83	16.14	38
39	14.70	14.88	15.08	15.30	15.53	15.78	16.05	16.34	16.66	39
40	15.15	15.35	15.56	15.77	16.01	16.27	16.56	16.86	17.19	40
41	15.61	15.81	16.03	16.26	16.50	16.78	17.07	17.39	17.73	41
42	16.07	16.28	16.51	16.75	17.01	17.29	17.59	17.93	18.28	42
43	16.55	16.76	17.00	17.25	17.52	17.81	18.13	18.47	18.84	43
44	17.03	17.26	17.50	17.76	18.04	18.34	18.67	19.02	19.42	44
45	17.53	17.76	18.01	18.28	18.58	18.89	19.23	19.60	20.01	45
46	18.03	18.27	18.53	18.81	19.11	19.44	19.80	20.18	20.60	46
47	18.53	18.76	19.06	19.35	19.66	20.00	20.37	20.77	21.21	47
48	19.05	19.31	19.60	19.89	20.22	20.57	20.96	21.37	21.83	48
49	19.58	19.85	20.15	20.46	20.80	21.16	21.56	22.00	22.47	49
50	20.11	20.40	20.70	21.08	21.38	21.76	22.18	22.63	23.11	50
51	20.66	20.95	21.28	21.61	21.98	22.38	22.80	23.27	23.78	51
52	21.22	21.52	21.85	22.20	22.58	22.99	23.43	23.92	24.45	52
53	21.79	22.10	22.45	22.81	23.20	23.63	24.10	24.60	25.15	53
54	22.37	22.70	23.05	23.42	23.83	24.28	24.76	25.28	25.85	54
55	22.95	23.29	23.66	24.05	24.48	24.94	25.44	25.98	26.57	55
56	23.55	23.91	24.29	24.71	25.15	25.61	26.13	26.70	27.32	56
57	24.16	24.53	24.92	25.36	25.81	26.30	26.84	27.43	28.06	57
58	24.79	25.17	25.58	26.02	26.50	27.01	27.56	28.18	28.84	58
59	25.43	25.82	26.25	26.70	27.20	27.73	28.31	28.93	29.63	59
60	26.07	26.49	26.93	27.40	27.91	28.46	29.06	29.72	30.43	60
61	26.74	27.17	27.62	28.11	28.65	29.21	29.83	30.52	31.25	61
62	27.42	27.87	28.34	28.85	29.40	29.99	30.63	31.36	32.11	62
63	28.12	28.58	29.06	29.60	30.16	30.78	31.45	32.18	32.97	63
64	28.81	29.29	29.79	30.35	30.94	31.57	32.27	33.03	33.85	64
65	29.54	30.04	30.56	31.14	31.75	32.41	33.12	33.91	34.76	65
66	30.28	30.79	31.33	31.92	32.55	33.24	33.98	34.79	35.68	66
67	31.03	31.56	32.13	32.74	33.40	34.10	34.88	35.72	36.63	67
68	31.80	32.34	32.93	33.56	34.25	34.98	35.79	36.66	37.60	68
69	32.58	33.15	33.76	34.41	35.12	35.88	36.71	37.61	38.61	69
70	33.38	33.97	34.60	35.28	36.01	36.80	37.66	38.60	39.63	70
71	34.21	34.81	35.47	36.16	36.92	37.74	38.63	39.60	40.67	71
72	35.05	35.67	36.36	37.08	37.87	38.72	39.64	40.64	41.75	72
73	35.90	36.55	37.25	38.01	38.82	39.71	40.66	41.70	42.84	73
74	36.78	37.45	38.18	38.96	39.80	40.71	41.71	42.79	43.97	74
75	37.68	38.37	39.13	39.93	40.81	41.75	42.78	43.89	45.12	75
76	38.59	39.31	40.09	40.93	41.83	42.81	43.87	45.03	46.31	76
77	39.54	40.29	41.09	41.95	42.89	43.91	45.01	46.21	47.54	77
78	40.50	41.27	42.11	43.00	43.97	45.02	46.17	47.42	48.77	78
79	41.47	42.28	43.14	44.07	45.07	46.16	47.34	48.63	50.05	79
80	42.48	43.31	44.20	45.16	46.19	47.32	48.55	49.89	51.35	80
81	43.51	44.36	45.29	46.28	47.37	48.53	49.80	51.18	52.71	81
82	44.55	45.45	46.40	47.43	48.55	49.75	51.07	52.50	55.13	82
83	45.64	46.55	47.55	48.62	49.77	51.03	52.38	53.87	55.50	83
84	46.73	47.68	48.72	49.82	51.01	52.31	53.71	55.25	56.93	84
85	47.86	48.85	49.91	51.05	52.29	53.63	55.08	56.68	58.42	85
86	49.01	50.04	51.14	52.33	53.60	54.99	56.50	58.15	59.96	86
87	50.20	51.26	52.40	53.63	54.95	56.38	57.95	59.66	61.53	87
88	51.41	52.50	53.68	54.95	56.32	57.80	59.43	61.19	63.13	88
89	52.66	53.79	55.01	56.32	57.74	59.28	60.96	62.79	64.79	89
90	53.92	55.10	56.36	57.73	59.19	60.78	62.52	64.41	66.49	90
91	55.23	56.45	57.72	59.16	60.69	62.33	64.13	66.10	68.24	91
92	56.56	57.81	59.17	60.62	62.19	63.90	65.76	67.79	70.02	92
93	57.94	59.23	60.63	62.10	63.76	65.53	67.46	69.56	71.87	93
94	59.34	60.68	62.13	63.69	65.37	67.20	69.19	71.37	73.77	94
95	60.77	62.17	63.66	65.27	67.01	68.91	70.98	73.23	75.71	95
96	62.25	63.68	65.23	66.88	68.70	70.66	72.80	75.14	77.69	96
97	63.75	65.23	66.83	68.56	70.42	72.46	74.65	77.08	79.74	97
98	65.30	66.85	68.50	70.29	72.21	74.32	76.62	79.13	81.87	98
99	66.90	68.48	70.20	72.06	74.05	76.23	78.60	81.17	84.05	99
100	68.51	70.16	71.93	73.85	75.91	78.16	80.63	83.31	86.26	100
101	70.19	71.89	73.72	75.70	77.85	80.17	82.71	85.50	88.57	101
102	71.91	73.67	75.56	77.61	79.83	82.24	84.87	87.76	90.92	102
103	73.68	75.49	77.46	79.57	81.86	84.36	87.08	90.07	93.35	103
104	75.47	77.35	79.39	81.57	83.96	86.54	89.36	92.45	95.86	104
105	77.31	79.26	81.36	83.63	86.08	88.76	91.68	94.88	98.40	105
106	79.21	81.23	83.40	85.75	88.29	91.07	94.09	97.42	101.1	106
107	81.17	83.26	85.51	87.94	90.58	93.44	96.57	100.0	103.8	107
108	83.16	85.33	87.65	90.16	92.89	95.87	99.10	102.7	106.6	108
109	85.22	87.46	89.80	92.46	95.30	98.36	101.7	105.4	109.5	109
110	87.34	89.65	92.14	94.83	97.75	100.9	104.4	108.3	112.5	110
111	89.49	91.88	94.45	97.26	100.3	103.6	107.2	111.1	115.5	111
112	91.72	94.19	96.85	99.74	102.9	106.3	110.0	114.1	118.7	112
113	94.02	96.57	99.33	102.3	105.6	109.1	113.0	117.2	121.9	113
114	96.36	99.01	101.9	105.0	108.3	112.0	116.0	120.4	125.3	114
115	98.78	101.5	104.5	107.7	111.2	115.0	119.1	123.7	128.8	115
116	101.3	104.1	107.2	110.5	114.1	118.0	122.3	127.1	132.3	116
117	103.8	106.8	109.9	113.4	117.1	121.2	125.6	130.6	136.0	117
118	106.4	109.5	112.7	116.3	120.2	124.4	129.0	134.1	139.8	118
119	109.1	112.2	115.6	119.3	123.3	127.7	132.5	137.8	143.6	119
120	111.9	115.1	118.7	122.5	126.6	131.2	136.2	141.6	147.7	120

NOMENCLATURE

B = Barometric pressure, in. Hg.
B_e = Barometric pressure used in calculations involving comparison with basic data at 30.0 in. barometer, in. Hg.
e = $2{,}800 - 1.3t_w$
f = $(30.0 - B_e)/29.4$
G = Rate of air flow through tower, lb. bone dry air per min.
H = Air humidity, lb. of water vapor per lb. bone dry air
H' = Humidity value used in computing H'_s, lb. per lb.
H_e = Humidity for problem condition at B_e, lb. per lb.
H_s = Humidity at B for partial pressure of water vapor for conditions B_e, t, and t_w, lb. water vapor per lb. dry air.
H'_s = Humidity value used in plotting Fig. 4, lb. per lb.
H_w = Humidity at the saturated wet-bulb, lb. per lb.
L = Water rate through cooling tower, lb. per min.
p_e = Partial pressure of water vapor in the main air stream, in. Hg.
p_s = Partial pressure of water vapor at B_e, in. Hg.
p_w = Saturated pressure of water vapor at the wet-bulb temperature, in. Hg.
Δp = $p_s - p_e$
r_w = Latent heat of vaporization of water vapor at t_w, B.t.u. per lb.
s = Humid specific heat of air-water mixture, B.t.u. per deg. F. and lb. of dry air.
t = Temperature of the air-water mixture, or dry-bulb temperature, deg. F.
t_w = Wet-bulb temperature, deg. F.
t'_w = Apparent wet-bulb temperature determined by the use of the Σ' function.
Δt = Temperature step increment, deg. F.
T = Bulk temperature of the water, deg. F.
Σ = The Sigma Function, in main air stream, B.t.u. per lb. dry air.
Σ' = An approximate value of the Sigma Function, computed by use of Eq. (41), and uncorrected for humidity changes, B.t.u. per lb. dry air.

SUBSCRIPTS

e = Conditions at B_e when compared with conditions at $B = 30.0$ in.
w = Wet-bulb conditions.
1 = Conditions at air entrance and water exit of a counter-flow tower.
2 = Conditions at water entrance and air exit of a counter-flow tower.

bulb = 115 deg. F.; and $p_w = 0.7392$ in. Hg. The use of Eq. (7) yields

$p_s = 0.3528$ in. Hg.

By Eq. (6), $H_1 = 0.0928$ lb. of water per lb. of dry air.

As a means of comparison, the humidity chart is used to compute the humidity. For the conditions of the problem, the value of H_{e1} is 0.0075 lb. This value is multiplied by 30/24, the ratio of the barometric pressures. The resulting humidity is then $0.0075 \times 30/24$, or 0.0094 lb. of water. For the example under consideration, the degree of accuracy resulting from the humidity chart method is evident.

The polygon shows that H_{e2} is 0.0195 lb. water. The value of H_{e1} was found to be 0.0075 lb. The pickup is computed from the chart readings and the barometric pressures. The values are substituted in Eq. (42): Pickup = 0.0150 lb. of water per lb. of dry air. Since the original ratio of L_2/G was 1.15, the percentage of pickup is $(100 \times 0.0150)/1.15$, or 1.30 percent.

Eq. (26) is the true equation for the computation of the sigma function of the air which leaves the apparatus. The value of H_1 for the example has been found to be 0.0094 lb. of water per lb. of dry air. The value of H_2 is BH_{e2}/B_e. In this case, $H_2 = (30 \times 0.0195)/24$, or $H_2 = 0.0244$ lb. of water. The values for use in Eq. (26) are: $L_2/G = 1.15$; $T_2 = 90$ deg. F.; $T_1 = 80$ deg. F.; $\Sigma_1 = 37.66$; $H_2 = 0.0244$; $H_1 = 0.0094$; $t_{w2} = 80.5$ deg. F.; and $t_{w1} = 70.0$ deg. F.

Substitution of these quantities gives $\Sigma_2 = 48.81$ B.t.u. per lb. of dry air. The corresponding value of the wet-bulb is found by interpolation in Table II; the revised temperature is 80.2 deg. F. The first trial value of t_{w2} was established through the approximate method which used Σ'_2.

Although the correction is small, its effect should be of interest. The polygon crosses the wet-bulb line of 80.2 deg. F. at a dry-bulb of 97.3 deg. F. and a humidity of 0.0192 lb. of water per lb. of dry air. The pickup is reduced to 0.0146 lb. of water; and the use of the Σ'_2 value has introduced a variation of less than 3 percent into the computation of the pickup. The true percentage of pickup is 1.27 percent. In view of these comparisons, the use of the Σ'_2 function is indicated as a practical design value to be used in place of the more involved value of Σ_2.

The usual rule of thumb method for estimation of evaporation is to allow 1.0 percent evaporation for each ten degrees of water cooling range. This allowance is based upon a latent heat of 1,000 B.t.u. per lb. of water evaporated. Specifications for modern forced convection cooling towers often limit the entrainment loss to 0.25 percent of the water circulated. The example which has been given shows an evaporation loss which is 27 percent greater than the loss which would be specified by this rule of thumb method. In this case, the error in the evaporative limitation might exceed the full value allowed for entrainment.

Where the cost or availability of make-up water is an important consideration, such a difference may be significant. Furthermore, specifications should not contain requirements which are inconsistent with the fundamental conditions of the problem. If the changing temperature of the dry-bulb equals the temperature of the contacted water at every point in the apparatus, the cooling is effected entirely by evaporation. However, whenever the dry-bulb exceeds the water temperature, the heating effect of the air opposes the evaporative cooling effect and the evaporation loss for a given cooling range, wet-bulb and barometer increases as the dry-bulb is increased.

CONCLUSIONS

1. The basic gas laws are the starting point for the setting up of the psychrometric structure.

2. The use of the sigma function of Carrier offers a rapid and practical basis for the study of psychrometric changes in a given apparatus.

3. The use of the Σ'_2 value as defined by Eq. (41) is justified for practical design.

4. The basic humidity chart for a barometric pressure of 30 in. may be used as a basis for other barometric conditions.

5. The psychrometric polygon is drawn on the field of the humidity chart; the change in the condition of the air as it passes through the apparatus is indicated by the polygon.

6. For ranges up to 10 deg. F., the outgoing condition of the air is closely identified on the humidity chart if a single, straight path line is drawn from the entering air condition to the saturated condition point for the average water temperature, and the point of intersection is located where this line crosses the wet-bulb line defined by Σ'_2.

7. Specifications for evaporation may be readily established by use of the psychrometric polygon.

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Thermal Properties of Mixed Acids

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Chem. & Met. INTERPRETATION

Nitration has again become one of the most important unit processes of chemical engineering. Whether in the production of smokeless powder and high explosives for war use or in the commercial manufacture of dyes and synthetic organic chemicals, the chemical engineer has frequent use for thermal data in calculating heat balances and similar operating factors. The enthalpy chart presented in this paper makes these thermal properties of mixed acids more readily available for practical use in calculations of this kind.—Editors.

MIXED ACID, a mixture of sulphuric acid, nitric acid, and water, is commonly used as the nitrating agent in commercial nitration reactions. These nitration reactions are the basis of our explosives industry and are also important in the production of dyes, dye intermediates and other industrial organic chemicals. The thermal properties of mixed acids are not readily available as some of the data are in French and many of the figures are not given in engineering units. The enthalpy chart presented here makes these thermal properties readily available and usable for heat balance and similar calculations.

Construction of Chart—Each set of data on heats of solution or dilution (1, 2, 4, 6, 7, 8, 10, 11, 12, 14*) was recalculated to obtain the relative enthalpy of one pound of solution at 32 deg. F. referred to each pure component at 32 deg. F. The relative enthalpies so computed were then plotted on a triangular ternary composition diagram (Fig. 1) and lines of constant enthalpy were drawn. In drawing these iso-enthalpy lines the data of McDavid (7), of Pretat (11), and of Rhodes and Nelson (12) were especially relied upon. Lines representing constant acid ratios were then drawn as indicated, starting at the acid ratio in question along the H_2SO_4—HNO_3 side of the triangle (0 percent H_2O) and extending to the H_2O corner. The intersections of these acid ratio lines with the iso-enthalpy lines were then used in plotting the ternary enthalphy data upon a pseudo binary basis. (Fig. 2).

The reliable experimental data (7, 11, 12) agree among themselves usually within 3 to 4 B.t.u. per lb. in overlapping regions and show no departure greater than 7 B.t.u. The final plot agrees with the more reliable data within 4 B.t.u. per lb. of solution in practically all cases.

Use of Chart—The ordinate of Fig. 2 is enthalpy in "B.t.u. per lb. of solution" and the abscissa is "percent by weight of total acid in the mixed acid solution." The enthalpy for a specific composition is obtained by interpolation between the lines of indicated nitric acid composition, being based on anhydrous HNO_3 + H_2SO_4, and for the total acid concentration as given along the abscissa. For example the line of 60 percent HNO_3 on this plot represents the enthalpy at 32 deg. F. of all mixtures of water with an acid mixture containing 60 parts nitric acid to 40 parts of sulphuric acid on the basis of anhydrous acid (HNO_3 + H_2SO_4).

The enthalpy of a mixed acid containing 30 percent HNO_3, 20 percent H_2SO_4, and 50 percent H_2O as read from the chart is —106 B.t.u. per lb. of solution. The steps involved are set forth in detail in Example A.

The enthalpy values as read from the chart are referred to the standard state of the pure components HNO_3, H_2SO_4 and H_2O, each having zero enthalpy at 32 deg. F. This reference

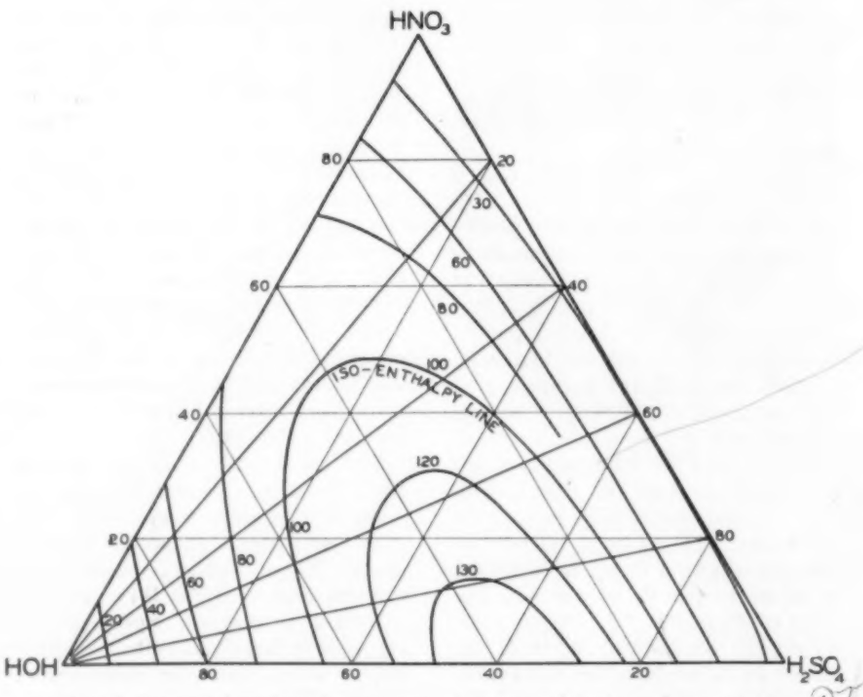

Fig. 1. Iso-enthalpy chart for mixtures of water, sulphuric and nitric acids.

* See bibliography at end of article.

state for water is the same reference state as for the steam tables, hence enthalpy values for pure water as read directly from steam tables may be used without modification in conjunction with values read from Fig. 2. For example, the relative enthalpy of water at 75 deg. F. may be read from steam tables as 43.0 B.t.u. per lb. This value may be used directly in the heat balance shown in Example B rather than calculating the relative enthalpy of the water as is done in the example. If steam or water vapor is involved in any operations the heat balance can be calculated using directly the data in the steam tables for the enthalpy of steam in connection with enthalpy data from Fig. 2.

Heat Balance—One advantage of the type of plot used for Fig. 2 is that a heat and material balance may be made directly upon it by means of straight lines. To illustrate the type of information which may be obtained graphically consider the mixing of one pound of an acid containing 40 percent H_2SO_4 and 60 percent H_2O with two pounds of an acid containing 7 percent H_2SO_4, 63 percent HNO_3, and 30 percent H_2O. Locating the two points represented by these compositions (See Example A for method of location) it is seen that the enthalpies of these two original mixtures are —108.5 and —87.5 B.t.u. per lb. respectively.

Since on such a figure a heat and material balance is represented by a straight line, a straight line (AB) drawn between these two points represents an enthalpy and material balance for the above mixture. Since there was one pound of 40 percent total acid (A) and two pounds of 70 percent total acid (B), the point corresponding to the final total acid is located on the line AB at a point two-thirds the distance from A to B, i.e. C, with a total acid concentration of 60 percent. The enthalpy of this final mixture is read along the enthalpy scale as —94.5 B.t.u. per lb. The enthalpy of —94.5 however represents for the final concentration a temperature above 32 deg. F. Therefore the percent HNO_3 cannot be read directly at this point C. The enthalpy of the final mixture at 32 deg. F. is read from the chart for a total acid concentration of 60 percent and a HNO_3 in the total anhydrous acid of 70.0 percent as —104.8. The final enthalpy of —94.5 is (—94.5 + 104.8 = 10.3 B.t.u.) 10.3 B.t.u. per lb. greater than the enthalpy of the final solution at 32 deg. F. Therefore 10.3 B.t.u. per lb. must be removed in the mixing of these two original solutions if it is to be accomplished isothermally at 32 deg. F. If no heat is removed the final temperature will be

$$32 \text{ deg. F.} + \frac{10.3}{Cp} = 32 \text{ deg. F.} + \frac{10.3}{.628} =$$

48.4 deg. F.

Plotted on Fig. 2 against the same abscissa but against different ordinates are the specific heat data for the system. From this figure, containing both 32 deg. F. relative enthalpies and specific heats, the enthalpy of any liquid mixture of nitric acid, sulphuric acid, and water may be readily calculated by reading the desired relative enthalpy at 32 deg. F. and the specific heat from the chart as has been indicated above.

The available data on heat capacities (3, 9, 13, 14) are all at substantially 70 deg. F. or room temperature. Therefore the heat capacities plotted in Fig. 2 are at 70 deg. F. but may be used over any temperature range until data for different temperatures are available.

Following are three examples illustrating the method of using Fig. 2.

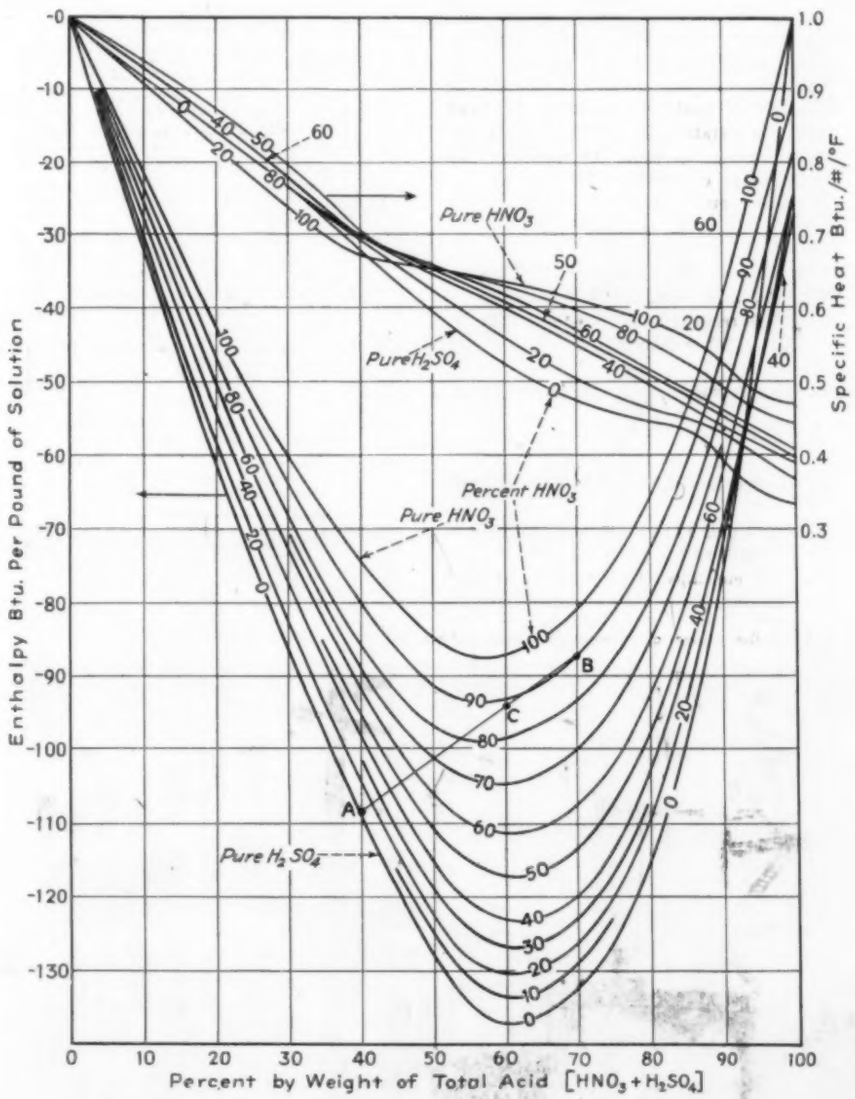

Fig. 2. Enthalpy of nitric-acid, sulphuric-acid and water mixtures.
(Standard state—pure components at 32 deg. F. Percent HNO_3 calculated on water-free basis. Assume specific heat same at all temperatures.)

EXAMPLE A

Find the relative enthalpy of a mixed acid of the following composition at 90 deg. F.:

HNO_3	30 percent
H_2SO_4	20 percent
H_2O	50 percent

Percent HNO_3 on anhydrous or water free basis $= \frac{30}{50} \times 100 = 60$ percent

Percent total acid = 50 percent

Then read from the chart at 50 percent on the abscissa and at 60 percent on the percent HNO_3 line H = —106 B.t.u./lb. solution and sp. ht. = .66 B.t.u./lb. solution/°F.

$H_{90°} = -106 + (90-32)\ (.66) = -67.7$ B.t.u./lb.

EXAMPLE B

Fresh acid for the mononitration of toluene is to be prepared of the following composition at 95 deg. F.:

62 wt. percent H_2SO_4
21 wt. percent HNO_3
17 wt. percent H_2O

The following materials are available:

95 percent H_2SO_4 at 75 deg. F.
70 percent HNO_3 at 75 deg. F.
Water at 75 deg. F.

The heat that must be removed in the formation of the above nitrating acid may be calculated by a heat balance. First it is necessary to determine the relative enthalpy of each of the reactants and of the mixed acid. The percent HNO_3 in the anhydrous acid of the fresh acid mixture equals $\frac{21 \times 100}{21 + 62} = 25.3$ percent.

and the percent total acid in the fresh acid mixture is 62 + 21 = 83 percent.

The following data are read from the chart:

	Sp.Ht.	Enthalpy at 32 deg. F.
Mixed Acid (M.A.)	.470	−98.7
95 percent H_2SO_4 (using 0 percent HNO_3 line)	.355	−44
70 percent HNO_3 (using 100 percent HNO_3 line)	.613	−81
Water	1.0	0

The relative enthalpy of each of the materials and the product may be calculated:

MA at 95 deg. F; H = −98.7 + .470 (95–32) = −69.1

95 percent H_2SO_4 at 75 deg.; H = −44 + .355 (75–32) = −28.7

70 percent HNO_3 at 75 deg.; H = −81 + .613 (75–32) = −54.6

water at 75 deg. F.; H = 0 + 1.0 (75–32) = +43.0

Basis 100 lb. M.A.

The amount of each material required

95 percent H_2SO_4 required = 62/.95 = 65.26
70 percent HNO_3 required = 21/.70 = 30.00
water required = 4.74
100.00

Enthalpy In

Reactants at 75 deg. F.

95 percent H_2SO_4 65.26 (−28.7) = −1,873
70 percent HNO_3 (30.0) (−54.6) = −1,638
H_2O (4.74) (+43) = 204
Heat to be added per 100 lb. final M.A. −3,603
−6,910

Enthalpy Out

Mixed acid at 95 deg. F.

Ma. (100) (−69.1) = −6,910
−6,910

Heat to be removed per lb. final M.A. = 3603/100 = *36* B.t.u./lb. M.A.

EXAMPLE C

The mononitration of toluene is to be carried out with the above M.A. at 95 deg. F. and the spent acid composition is to be 71.69 percent H_2SO_4, 2.31 percent HNO_3, and 26 percent H_2O by weight. The heat of reaction (decrease in enthalpy) for toluene to mononitro-toluene equals 610 B.t.u. per lb. of toluene (5). Assume that an excess of toluene is present and the charge is dumped when the acid concentration is reduced to 2.31 percent HNO_3 (toluene-free basis). To compute the quantity of heat that must be removed from the nitrator per 100 lb. M.A. in the initial charge in order to maintain the temperature constant at 95 deg. F.:

Basis 100 pounds M.A.

62 lb. H_2SO_4
21 lb. HNO_3
17 lb. H_2O

Wt. final acid = 62/.7169 = 86.5 lb.

lb. HNO_3 reacted = 21 − 86.5 × 2.31 = 21 − 2.0 = 19.0 lb.

lb. water formed = $\frac{19.0}{63} \times 18 =$ 5.43 lb. H_2O

lb. toluene reacted = $\frac{19.0}{63} \times 92 = 27.75$ lb.

Heat given off by reaction = 27.75 (610) = 16,910 B.t.u.

Relative enthalpy (H) for M.A. at start (95 deg. F.) = 100 (−69.1) = −6,910

The spent acid contains

H_2SO_4 62.00 lb. or 71.7 percent
HNO_3 2.00 lb. or 2.3 percent
Water 22.43 lb. or 26.0 percent
86.43 lb.

In the anhydrous spent acid the percent HNO_3 equals $\frac{2.3 \times 100}{74.0} = 3.11$ percent

and the percent total acid equals $\frac{(71.7 + 2.3) \times 100}{100} = 74.0$ percent. Reading from the chart and calculating, the total relative enthalpy of the spent acid equals: 86.43 [−126.5 + (95–32)(.47)] = −8380 B.t.u.

Enthalpy Balance

Enthalpy In		*Enthalpy Out*	
Mixed Acid	−6,910	Spent Acid	−8,380
Enthalpy Added by Nitration	16,910	Enthalpy difference	18,380

Therefore the total heat to be removed per 100 lb. M.A. charged equals 18,380 B.t.u.

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Mixed-acid production area in one of the large government-owned plants for nitrocellulose production.

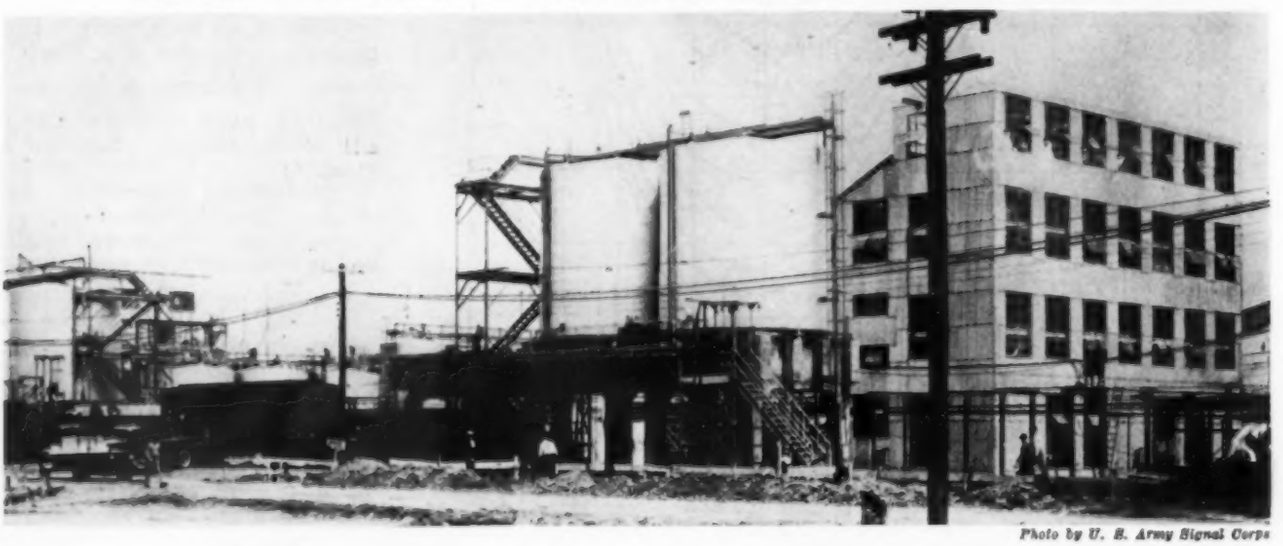


Photo by U. S. Army Signal Corps

Machinery, Materials and Products

CHEM & MET PROCESS EQUIPMENT NEWS

Wartime Precautions

SEVERAL new devices for protecting and blacking out windows are now available on the American market. One of these is the Meta-Fold blackout awning, manufactured by Acklin Stamping Co., Toledo, Ohio. This metal awning is installed on the outside of the building and consists of a series of telescoping metal segments which in the closed position form a semi-cylindrical shield over the window. When half opened, the shield serves the purpose of an ordinary awning and when completely opened, acts as a small cornice over the window. The galvanized steel segments are arranged to seal against each other with a light-proof joint. The covering is said to afford protection for the window against both blast and flying splinters.

The Obscurator protective blackout screen is manufactured by the Obscurator Co., Madison, N. J. This device consists of a number of hardboard panels installed in a wooden framework built to fit the window opening. A pulley and rope arrangement permits pulling all of the panels to the top when blackout is not necessary, thus presenting a 75 percent opening. When the window is to be blacked out, the panels are lowered, forming a solid screen filling the opening. Light-tight joints between the several panels prevent escape of light. The device is said to offer maximum protection to personnel and machinery from glass splinters and bomb fragments as well as a certain degree of protection against incendiary bombs. Furthermore, it is said to be weatherproof if the glass is broken and adaptable not only to vertical windows, but also to sawtooth roof and monitor windows.

For black-out lighting, Wabash Appliance Corp., Brooklyn, N. Y., has introduced a blackout bulb complying with the latest Civilian Defense requirements. The new bulb substitutes a deep orange color for the blue and red previously used, omits inside silvering, and has an improved type of heavy black silicate coating to prevent light leakage except from the small-area colored light outlet. This 15-watt bulb is said to permit room occupants to see each other plainly, as well to see obstructions.

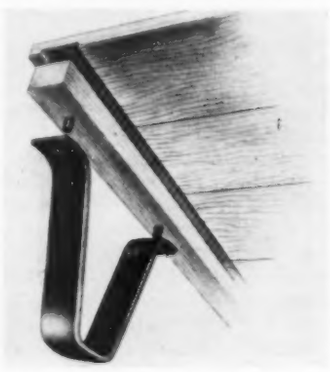
An invention of a DuPont Company engineer which is now being manufactured by Automatic Alarms, Inc., Youngstown, Ohio, can be applied to wire fences surrounding factories, permitting the guards to "hear" even the whisper of a person, the snip of a wire-cutter, or the sound of a pick adjacent to the wire. The so-called "acoustic fence" can be adjusted to screen out extraneous sounds, permitting other sounds to be detected at a distance of blocks or even several miles along the fence line from the receiving station. Furthermore, it is possible to tell instantly the location of any disturbance.

Meta-Fold blackout awning

Improved Skid Platform

AN ACCOMPANYING ILLUSTRATION shows the construction of a new steel-saving skid platform recently introduced by the Yale & Towne Mfg. Co., Philadelphia, Pa. This new platform, called the "Timber-Lock," was developed to minimize use of steel in the frame, which might be unobtainable for the purpose. This platform is made of selected tough oak with deep-cut grooves running the entire length of the platform deckboards. Into each of these grooves a hard oak leg-beam is tightly fitted with the beam and deck bound together with special cement-coated helical nails. The new construction is available in all standard widths and lengths, with plain or armored ends and four- or six-leg construction.

Skid platform construction



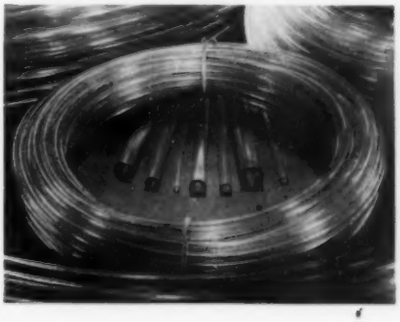
Industrial paging system

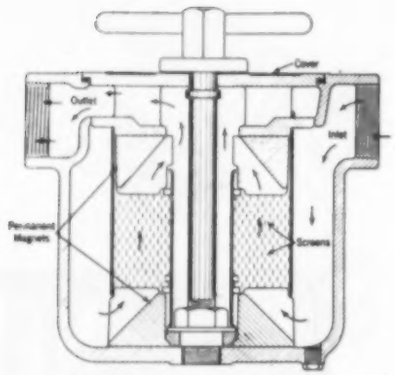
Industrial Paging System

A NEW TWO-WAY communication system, permitting paging messages to be originated from any station and broadcast to all stations, coupled with private two-way telephone-type conversations between any two or more points, is being marketed by Executone, Inc., 415 Lexington Ave., New York, N. Y. This system accommodates from 2 to 70 stations. Any person desiring to locate and converse with another person who may be at any point within the plant merely approaches the nearest station and talks into the mouthpiece of a telephone-type handset. Trumpet speakers at all other stations announce the call. The person hearing his name called approaches the nearest station and re-

Transparent Plastic Tubing

Tennessee Eastman Corp., Kingsport, Tenn., has announced the immediate availability of transparent Tenite tubing extruded in continuous lengths in diameters from 3/16 to ¾ in. Lengths of tubing may be coupled with the same standard flared fittings used for copper tubing, while large diameter tubing with wall thickness of 0.0625 in. can be threaded with standard pipe threading tools. This tubing in sizes up to ½ in. diameter, with a wall thickness of 0.035 in., is stocked in long coil lengths as shown in the picture. Over ½ in. in diameter the tubing is stocked in 12-ft. lengths. A 1-in. diameter tubing will be available shortly. The material is extruded from cellulose acetate butyrate plastic by Extruded Plastics Inc., Norwalk, Conn., and is distributed by Julius Blum & Co., 532 West 22d St., New York, N. Y.





Permanent magnet separator

moves the handset whereupon private two-way conversation is established. All trumpets are immediately automatically silenced.

However, since the other handsets remain connected into the system, round-table conferences of persons at any number of points are also possible. Several types of paging speakers are available, the type chosen for any location depending on the size and noise level of the office or factory area to be covered. This system is said to be equally suitable for broadcasting fire alarms, air raid warnings, instructions, etc.

Permanent Magnet Separator

CAPACITY up to 200 g.p.m. is claimed for a new permanent magnet Ferro-Filter designated as Model PQ-6, and recently announced by S. G. Frantz Co., 163 Grand St., New York, N. Y. The unit, which is designed for 3-in. pipe size connection, has a total height of 15⅝ in. It is intended particularly for the removing of harmful iron and steel particles from lubricating oil systems of pumps, engines and other heavy equipment.

Heavy Duty Mixer

TO ACCOMPLISH the mixing of extremely heavy materials, L. O. Koven & Bro., Jersey City, N. J., has developed a special mixing tank incorporating in the one unit three means of agitation. The container is all-welded, with a dished bottom. An outside jacket is provided for heating or cooling. A quick-opening handwheel is used to hold the manhole cover in place. The bottom outlet valve is of a type suited for quick discharge of heavy materials. The agitating mechanism consists of a vertical shaft coupled to a motor-driven speed reducer, with a three-blade ship-type propeller mounted substantially midway of the tank. At the bottom of the shaft is a turbine-type impeller, while the tank well itself carries inwardly projecting radial baffles mounted several inches away from the wall. The action of this combination of elements is said to be a continuous suction, dispersion, kneading and shearing cycle which rapidly disintegrates and distributes solids uniformly in the vehicle, or mixes two or more liquids of different specific gravities and viscosities.

Heavy duty mixer

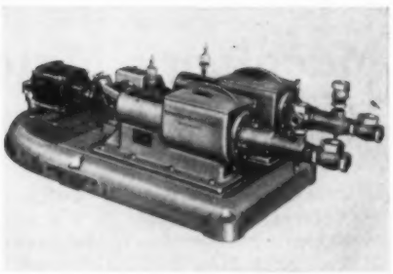
Remote Valve Control

NEW DESIGN for the remote manual control device for valves manufactured by The Foxboro Co., Foxboro, Mass., has recently been announced. The unit is employed also in the control of dampers and other pneumatically operated equipment. Its design harmonizes with the company's recently redesigned rectangular cases for recording and control instruments and when flush-mounted projects only $\frac{7}{16}$ in. from the instrument panel surface. To permit this, the setting knob and pressure indicator are recessed. The unit is specifically designed for dead-end service and is claimed to hold reduced pressures dependably and within narrow limits. Equipment can be controlled at distances up to 1,000 ft. from the unit, according to the manufacturer.

Proportioning Pump

A NEW proportioning pump, equipped with a liquid-sealed packing gland, for use where the liquid handled is corrosive or the service is otherwise severe, has been announced by Proportioneers, Inc., 9 Codding St., Providence, R. I. The construction of this liquid seal is as follows: Drive for the pump is provided by an adjustable-throw crank which reciprocates a cross-head through a connecting rod. The pump rod, which is attached to the cross-head, passes through a low-pressure packing into the liquid in the liquid-sealing vessel and thence through the high-pressure pump packing proper to the piston. Thus the rod is sealed from contact with the air, and destruction of the frame and working parts is prevented in the case of corrosive liquids. The seal also prevents build-up on the plunger in the case of liquids carrying suspended solids.

For example, when handling sulphuric acid, the sealing liquid is Russian mineral oil which prevents the escape of acid and attack on the frame and also prevents formation of sulphate crystals in the packing with consequent hardening. In handling hot solutions, the stuffing box can be kept cool by running a small stream of water through the seal. When handling materials such as rosin size solutions, which tend to build up on the plunger, the use of kerosene in the seal prevents build-up of rosin on the plunger. The pump has several other new features including an improved micrometer stroke adjustment, a shear pin on the driving crank to protect the speed reducer against overloading, and the use of needle bearings for both crank pin and wrist pin. The extra-deep stuffing box is provided with a replaceable bushing for depth adjustment and a Merco stick lubricator.



Duplex liquid-sealed proportioning pump

Remote valve control unit

Cement-Asbestos Pipe

MANUFACTURED by a patented high pressure process, the new Roxite cement-asbestos pipe now offered by United States Stoneware Co., Akron, Ohio, is said to have exceptionally high density and mechanical strength. In assembly, the pipe is coupled with this company's Flexlock sleeves and fittings and hence requires no special tools for assembling. A standard type is available for mildly corrosive liquids and for water as well as for the handling of fumes and gases. For more severe duty a grade of Roxite pipe impregnated or coated with synthetic corrosion-resisting materials is offered. Several synthetic resin coatings are available, to suit a wide variety of corrosive conditions. Standard pipe sizes range

from ¾ to 8 in. in lengths up to 14 ft., with 10 and 12 in. sizes made to special order. A complete line of standard fittings is also available. The pipe is intended for working pressures up to 150 lb.

Oven Air Heater

FOR THE HEATING of annealing ovens and lehrs, and other electrically heated ovens and furnaces, Westinghouse Electric & Mfg. Co., East Pittsburgh, Pa., has developed the new air heater unit shown in an accompanying illustration. The unit is designed for temperatures from 750 to 1,150 deg. F. and consists of a one-piece, nickel-chrome ribbon spirally wound around heavy porcelain insulators. Rated at 5 kw. for operation on 220-v. circuits, the complete heater is only 2½ in. thick and requires a space of 12x33 in. for mounting.

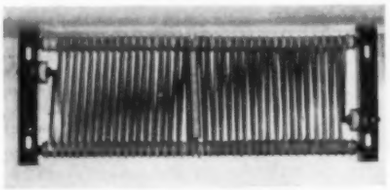
Flask Grip

A NEWLY DESIGNED grip for lifting flasks and carboys has been announced by Kellems Co., 1911 Park Ave., New York, N. Y. This grip is of woven wire, operating on the same principle as the cable and projectile grips made by this company. The principle, it will be observed, is that of the well-known woven finger-trap toy which, when tension is applied, grips the fingers with greater and greater pressure. The lever-operated release mechanism is clear from the accompanying illustration.

High Pressure Valve

DESIGNED for steam pressures to 1,500 lb. per sq. in. and temperatures to 950 deg. F., a new valve of integral-seat design has been announced under the name of Intex by the Edward Valve & Mfg. Co., East Chicago, Ind. Made in sizes from ¼ to 2 in., with socket welding, flanged or screwed ends, the valve incorporates several new design features. Both the integral seat and the contact face of the disk are Stellite-coated. The body has been so designed that the distribution of metal around the flow areas is said to equalize heating and cooling effects and assure negligible distortion. The bonnet studs are of equal length to assure a tight bonnet joint. The swivel plug disk is said to prevent binding and to be non-spinning. The body and disk are of carbon molybdenum steel, the yoke of cast bronze and the stem of stainless steel.

Electric air heater



"Cable-Grip" flask lifter

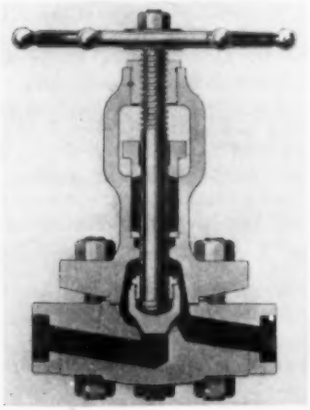
Condensate Controller

FOR CONTINUOUSLY CHECKING the purity of condensate in industrial steam plants, Leeds & Northrup Co., 4934 Stenton Ave., Philadelphia, Pa., has introduced a new automatic signalling condensate controller which is used where indicating and recording of condensate purity are not needed. Signal lights at the instrument show whether the condensate is of specified minimum purity and safe to use again, or whether it is below this limit and should be diverted to waste. If desired, the instrument can operate external warning bells or lights, or can operate automatically a two-position control by regulating a motor-driven valve in the condensate line to dump the impure condensate. The instrument, which operates on electrical conductivity of the condensate, can also be used to measure the conductivity by means of a dial setting.

Equipment Briefs

A HIGH-STRENGTH cast iron known as GarDurloy has recently been announced by Gardner-Denver Co., Quincy, Ill. This material, now used in the improvement of the company's products, is said to be chemically similar to other cast irons but to achieve its special properties largely through control of the metallurgical reactions in the furnace and through the elimination of variables by precise technique in the treatment of the molten metal. One form of the material is said to have a tensile strength, as cast, ranging from 57,500 to 65,000 lb., with a Brinell hardness in the range from 250 to 265. Other forms are produced with other properties accentuated.

Integral-seat valve

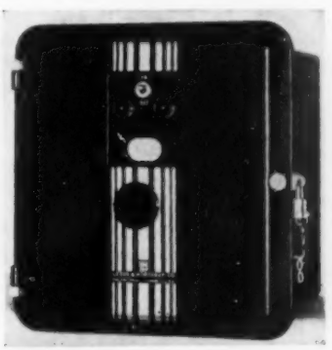


ADDING to its line of recently introduced Electrifugal single-unit pumps, Allis-Chalmers Mfg. Co., Milwaukee, Wis., has announced a new 25-hp. unit. Like other members of the line, the pump is built with motor and pump on a single shaft and in one housing. The design saves one-third of the space and offers other advantages such as lower pumping cost, easier installation, less vibration and less wear. The complete line now encompasses sizes ranging from ½ to 25 hp.

AN IMPROVED recovery still for chlorinated solvents of the type used in vapor degreasers has been announced by Phillips Mfg. Co., 340 West Huron St., Chicago, Ill. The still is fully automatic in operation and is electrically heated, with a forced-draft air-cooled condenser. A float switch operating a green pilot lamp automatically energizes the heater and starts the condenser cooling fan when dirty solvent has been poured into the pot to the proper level. When the liquid level drops to a lower limit, the float switch cuts off the heater and the pilot lamp. When the residue in the bottom reaches a predetermined specific gravity, and temperature indicating substantially complete solvent recovery, the heater is de-energized and a red pilot lamp signals the operator to dump the residue before again filling the pot.

TWO NEW rotating type limit switches have recently been announced by General Electric Co., Schenectady, N. Y., one type being for Class 1 Group D hazardous gas locations, and the other for applications requiring a water-tight switch. The mechanism of the switch is adjusted to operate the contacts between a minimum of one-half turn of the driving shaft, and a maximum of 120 turns. Over-travel will not harm the switch mechanism. The contacts are of a double-break, fine-silver, type

Automatic condensate controller



with a self-cleaning feature. One double-break contact is located at each end of the travel and can be set to be normally closed, or normally opened, without additional parts.

AN ELLIPTICAL shaped lighting fixture providing a wide lateral distribution of light has been developed by Goodrich Electric Co., 4600 Belle Plaine Ave., Chicago, Ill., for outside protective lighting around industrial plants. The unit conforms with FBI specifications. Known as the Elipso Standlite, it casts a brilliant barrier of light around property lines without illuminating buildings and grounds. One type delivers light laterally, another type provides a slight forward throw. Fixtures are porcelain-enameled and designed for mounting on 2-in. pipe.

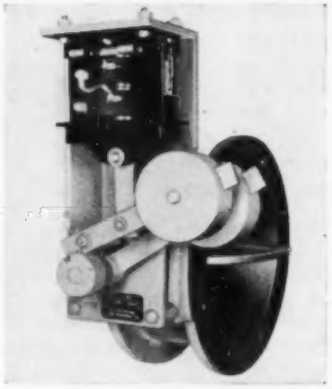
FOR LOW-TEMPERATURE laboratory work and special storing and aging operations, Jewett Refrigerator Co., 28 Letchworth St., Buffalo, N. Y., has announced a sub-zero Cold Treater refrigerator capable of maintaining temperatures down to −35 deg. F. These refrigerators are built in 3 and 6 cu.ft. capacities, with a self-contained sealed condensing unit ready to plug in and use. Standard control maintains temperatures from +5 deg. down to −10 deg. F. A special control gives temperatures from +20 to −35 deg. F.

Improved Pumps

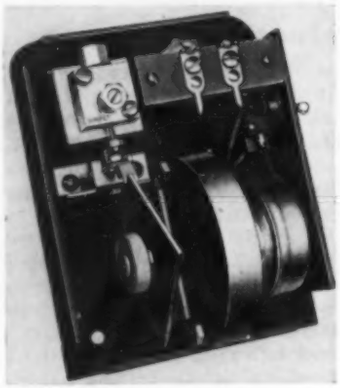
SEVERAL PUMP improvements have recently been announced by the Blackmer Pump Co., Grand Rapids, Mich. One is a hand-operated metering unit, designed primarily for the dispensing of oil, paint, solvents and similar liquids from under-floor storage in industrial stock rooms. The pump shown in the accompanying illustration handles 20 g.p.m., with other units of 7 to 25 g.p.m. available. The dial face of the meter is calibrated in pints, one revolution of the hand indicating a quart. By means of a reset device, quantities less than quarts can be measured. The pumping unit is this company's standard geared type rotary pump of swinging-vane design.

The company has also announced a complete new line of direct-connected rotary pumps in capacities of 5, 10 and 20 g.p.m. for pressures up to 100 lb. per sq. in. The unit consists of a pump mounted on a bed plate for flexible coupling to an electric motor, steam turbine or gasoline engine. Belt drive arrangements are also available. The pump is equipped with a bypass capable of handling its entire capacity. In addition, the company has announced a new line of pipe-line strainers, intended originally for use with the company's rotary pumps, but equally well suited, it is claimed, for other applications. The strainers are of the basket type, with both cast iron and bronze bodies available, which may be steam-jacketed if desired.

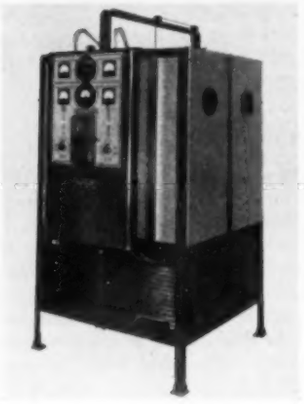
Hand metering pump



Solenoid butterfly valve



Repeating cycle timer



Twin-arc weathering unit

Repeating Cycle Timer

A SIMPLE timing device for purging condensate from various kinds of steam-heated equipment, which operates in conjunction with a diaphragm-motor-operated reverse-acting condensate valve has been announced by Taylor Instrument Cos., Rochester, N. Y. The new unit is known as the "Blow-Down Timer" and, when used in conjunction with suitable temperature or pressure control of the application, is said to permit the admission of fresh steam without effecting an appreciable pressure change within the apparatus. The device permits control of the duration as well as the period of the blown-down.

Butterfly Valve

A NEW solenoid-operated butterfly valve, designed particularly to eliminate wartime hazards, has been announced by R-S Products Corp., 4530 Germantown Ave., Philadelphia, Pa. This valve provides two-position control, either automatic opening or wedge-tight shut-off in case of electric power stoppage. In the open position, the butterfly vane is held open by the magnetic action of the solenoid. When the electric power fails or is intentionally disconnected, a trigger is tripped and a counterweight closes the valve tightly. To protect from fire due to incendiary bombing, for instance, the valve installed in a chemical or gas line would be set for automatic closing. A slight change in the setting of the parts makes possible automatic opening on disconnection. A variety of sizes is made in any desired construction material for gas, air, steam, oil and hydraulic use.

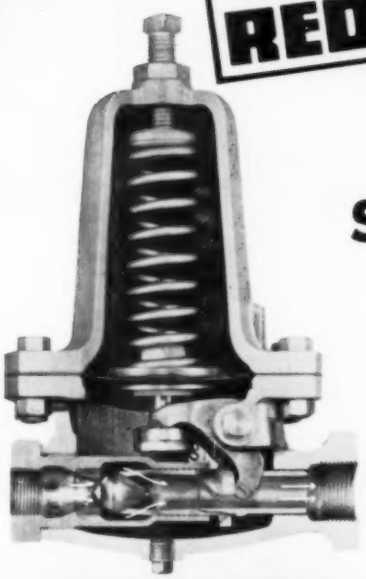
Weathering Tester

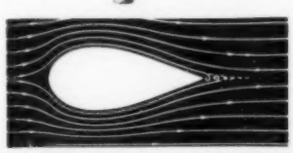
FOR ACCELERATED outdoor weathering tests, to determine within a few weeks the results of months of outdoor weathering, Atlas Electric Devices Co., 397 West Superior St., Chicago, Ill., has introduced a new twin-arc Weather-Ometer which is said to duplicate the action of outdoor weathering by combining the effects of sunlight, rain, heavy dew and thermal shocks. Increased testing speed as compared with earlier models results from increasing the active light at the specimen, and the coordination of thermal shocks produced by a cold water spray. A cycle control governs the light and thermal shock periods automatically. The cycle can be modified for various materials such as bitumens, paints, lacquers, varnishes, plastics, fabrics and other substances to be tested. Operation being automatic, the manufacturer claims that no attention is required other than to inspect the samples and reload the arc units once each 24 hours. Economical operation is claimed, with a total cost of carbon and current consumption amounting to only $1.20 per 24 hour day.

Eliminating

LOST PRODUCTION HOURS DUE TO "TIME OUT" FOR VALVE TROUBLES . . .

CASH STANDARD *Streamlined* TYPE 1000 PRESSURE REDUCING VALVE





HERE'S THE "1000" FLOW PATTERN
The Streamlined form of the inner valve eliminates turbulence. It produces the flow pattern shown above which makes for maximum capacity when it is needed most and permits accurate pressure control under toughest working conditions.

You can find out full details on all of the Type 1000 benefits by reading Bulletin "1000" —send for it!

Contributes toward SPEEDIER PRODUCTION

Today, with speed in output the keynote of American Industry, trouble-free, smooth performance of equipment is essential to maintain schedules. Keeping idle hours down to the very minimum is a vital need in any type of production.

Because of these very things, the CASH STANDARD Streamlined Type 1000 Reducing Valve has a place of importance in industry's fast-operating set-up . . . it is an immediate answer to the practical elimination of "time-out" periods.

When this valve was first designed, 'round-the-clock service — month in and month out was the objective. How well the Streamlined Type 1000 fits into the pace-setting production picture now is seen by its no-trouble, maintenance-free operation for years past.

Among the benefits users get with it are: maximum capacity when needed most — accurate pressure control under toughest working conditions — elimination of failures — cost-saving operation.

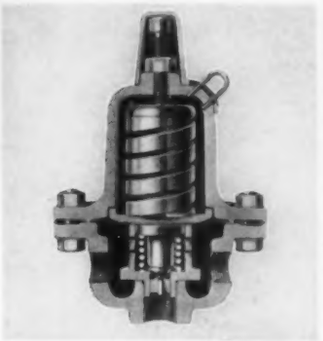
A. W. CASH COMPANY
DECATUR, ILLINOIS

CASH STANDARD CONTROLS . . VALVES

A CASH STANDARD "GET ACQUAINTED" COLUMN

Question: **"Don't you people make anything besides that Streamlined Valve you talk about so much?"**

Answer: **"Yes Sir; we do! And we propose to picture one or two of them here each time."**



Cash Standard Type Q Relief Valve; maintains constant upstream pressure by relieving into lower downstream pressures, regardless of variations in downstream pressure. For steam, water, air, oil, many gases. (Similar valve for refrigeration fluids.)

Iron or bronze bodies; bronze trim; pressures up to 350 lbs.; top temperature 500° F. Screwed ends; sizes ¼" to 2"

Cash Standard Type 4190 Valve; holds constant back pressure on inlet side regardless of variation in outlet pressure or changes in load. A multiport, large capacity valve. Used on suction line in refrigeration practice. Also used extensively as bypass valve for oil pumps.

Iron or bronze bodies; iron trim. Screwed ends ½" to 2"; flanged ends 1¼" to 6".

Get Free Bulletins on Above . . . Write to A. W. CASH COMPANY DECATUR, ILL.

Soap and Glycerine

MODERN SOAP AND GLYCERINE making may be exemplified by the works of the Manhattan Soap Co. at Bristol, Pa. This plant was greatly enlarged and completely modernized recently.

The raw materials, tallow and coconut oil, are refined and bleached to remove suspended matter and soluble coloring materials. While the same equipment is used for both tallow and oil, different adsorbent combinations (activated earth and carbon) are used. Tallow and oil are not bleached to the same degree. After filtration these materials are charged into a soap kettle when the fats are saponified to give the soap. Glycerine is produced by hydrolysis. The soap is "grained out" by the addition of salt or brine. Several washes remove the glycerine and lye. A finishing or final change is used to get the soap in such condition that the soaps of the lower fatty acids separate from those of the higher acids and both soaps separate from excess liquid. After the contents of the kettle has settled there are two layers of soap of different appearance and fatty acid content. The "neat" soap is the upper layer and below it is a slightly darker soap in which coloring matter and other impurities are concentrated. This layer is known as "nigre." It is reboiled to remove salt and caustic and impurities, and is then made into laundry soap flakes.

The neat soap or hot white liquid soap layer is filtered and pumped to the packaging building. The soap is solidified on a chilling roll and, in the form of flakes, is passed through a tunnel dryer where the moisture is reduced from 30 to 14 percent. To the partially dried soap in an amalgamator are added perfume, anti-oxidants and pigments. The mass is then blended and worked on several plodders. It is extruded from the final plodder, cut into blanks, and pressed into cakes.

The lye-glycerine solutions from the soap kettles are treated with alum to coagulate and remove soap and albuminous matter that may remain. The glycerine is concentrated to almost 40-45 percent in double-effect evaporators and is then fed into a single-effect for concentration to 80 percent soap-lye crude which is sold to refiners.

CHEMICAL & METALLURGICAL ENGINEERING

May, 1942

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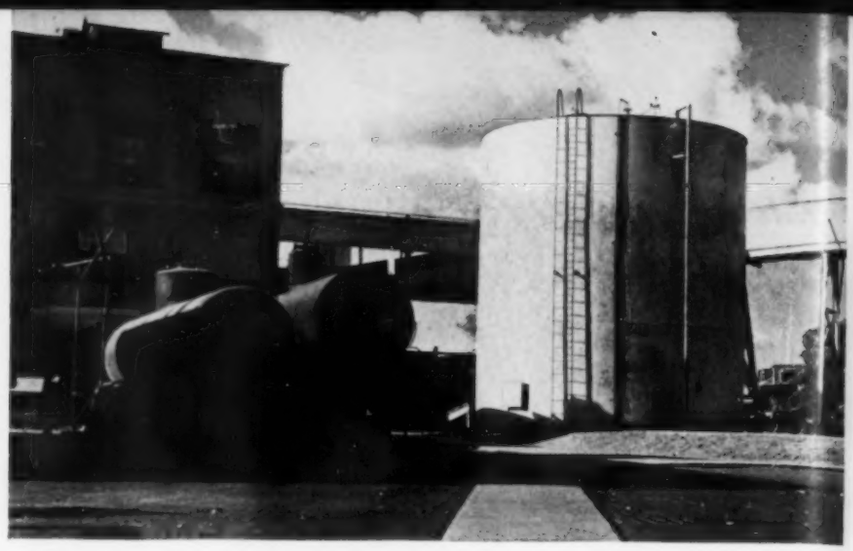
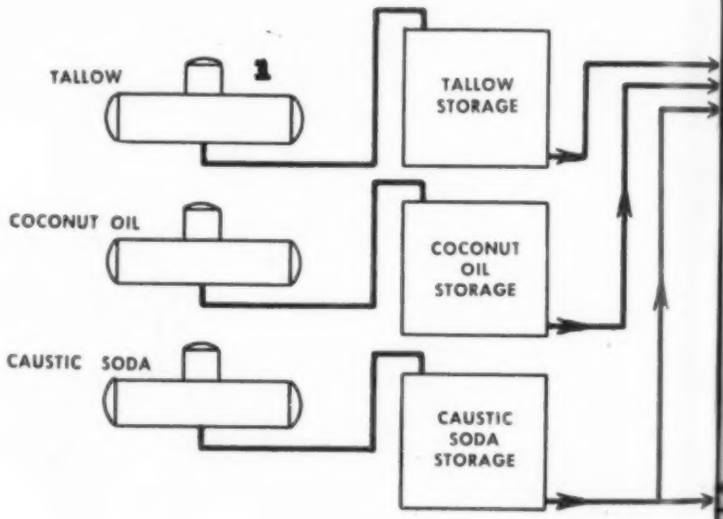
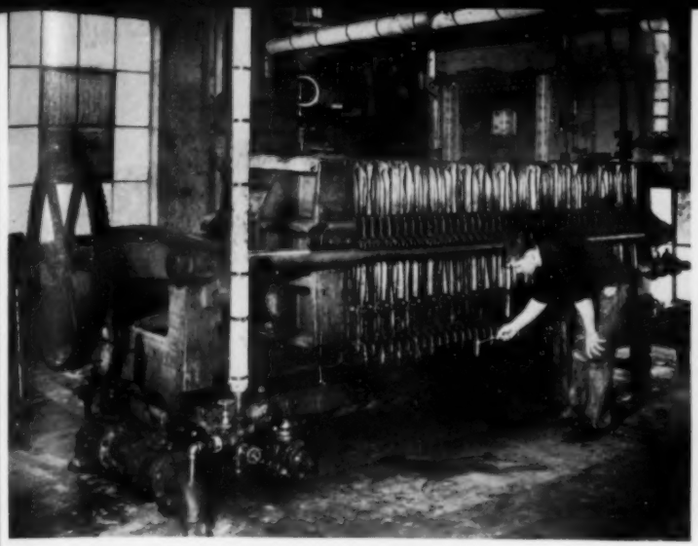


1 Part of the raw materials storage facilities at the Bristol, Pa., plant of the Manhattan Soap Co. Bridge connects production and packaing buildings



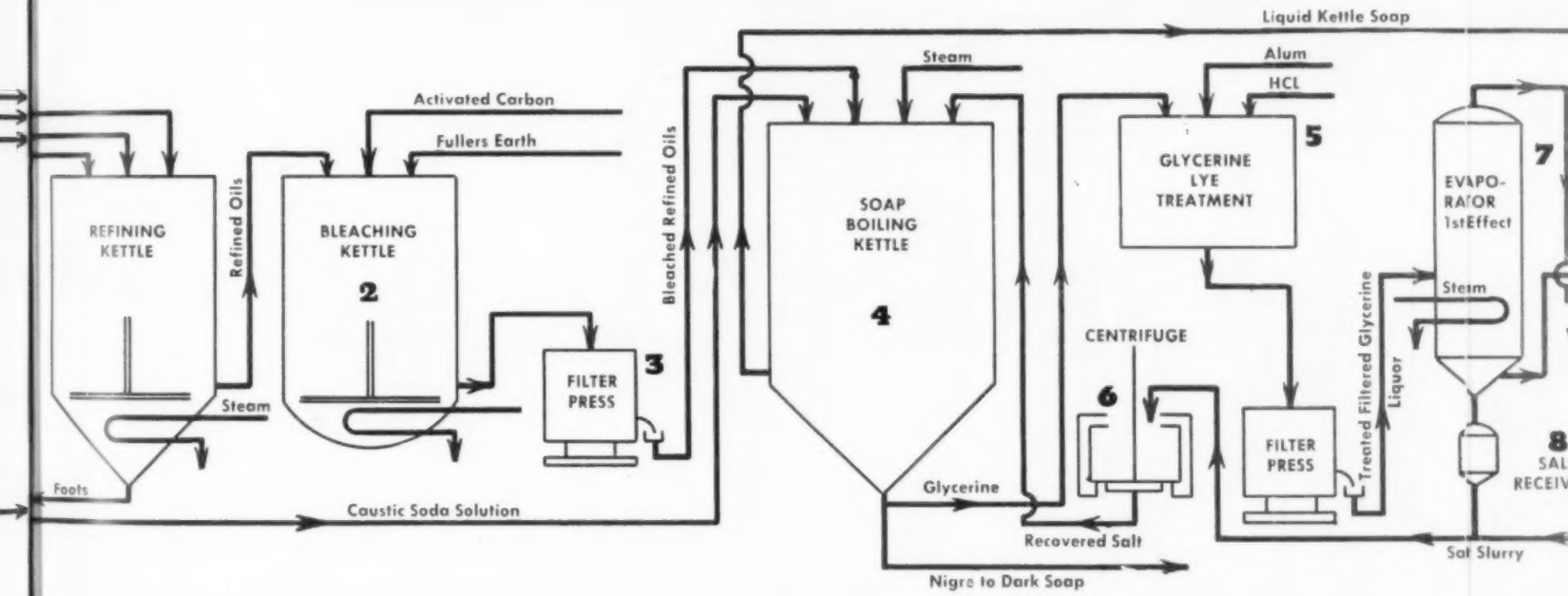
2 Tallow and coconut oil are refined, and then bleached with different combinations of activated earth and carbon, and to different color standards



3 The slurry is filtered and the clear filtrate flows by gravity to storage tanks on the floor below

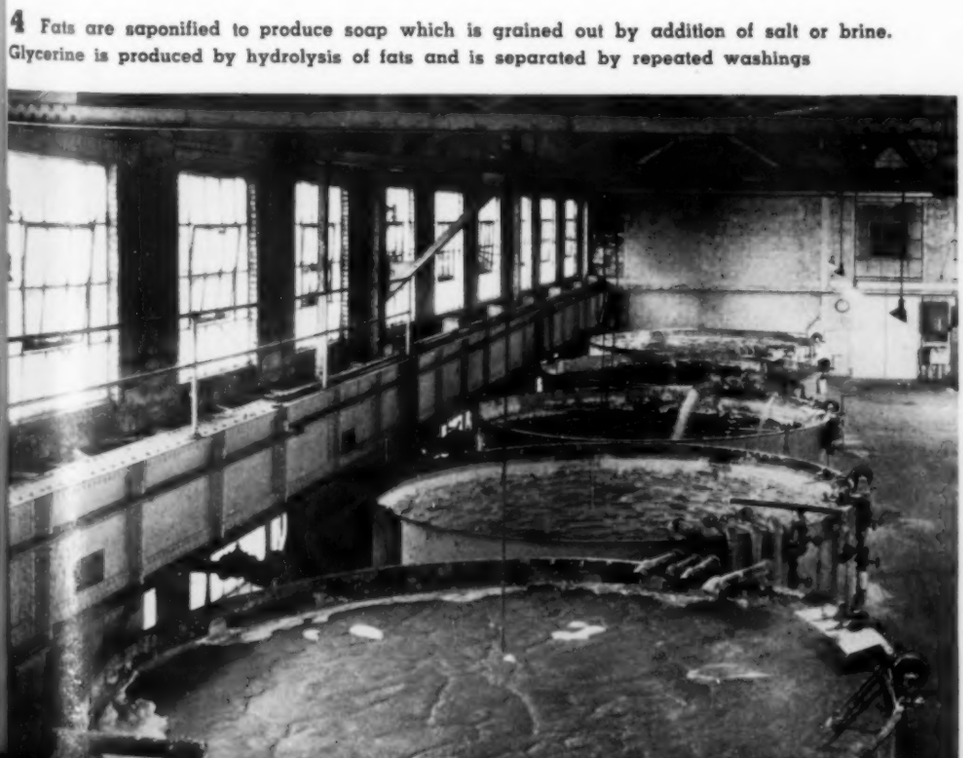
5 Steel and cypress storage tanks hold lye-glycerine solutions from the soap kettles. Wood is used for solutions to be treated with ferric chloride or hydrochloric acid

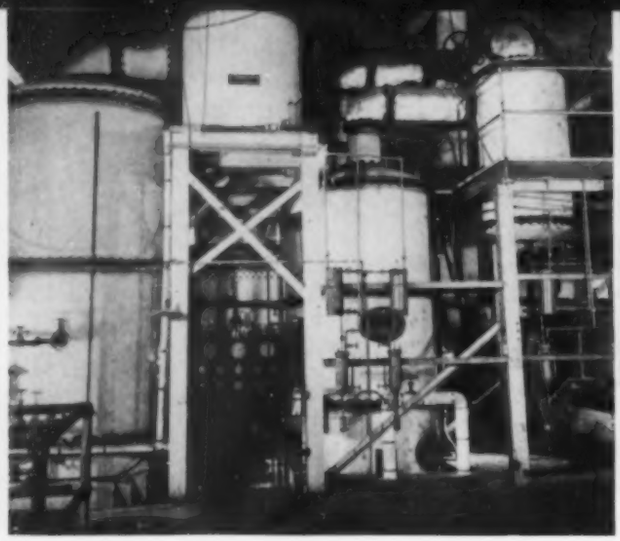
7 perce



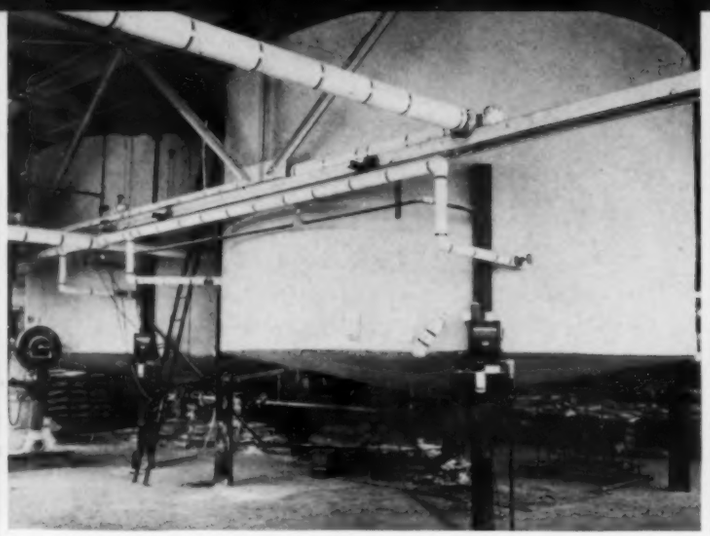
4 Fats are saponified to produce soap which is grained out by addition of salt or brine. Glycerine is produced by hydrolysis of fats and is separated by repeated washings

6 Salt is separated in the centrifuge, washed, and then dumped a belt conveyor below which carries it to brine tanks in the base



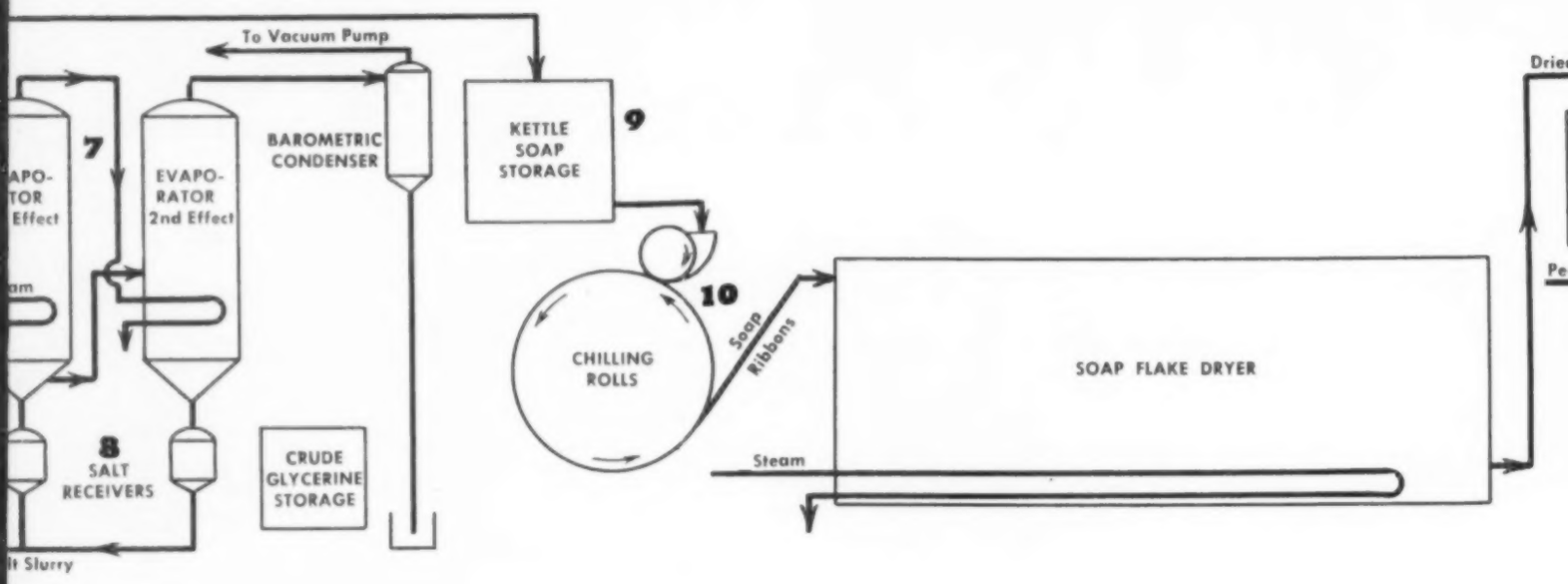


7 Solutions containing glycerine are concentrated to 80 percent crude in double- and single-effect evaporators



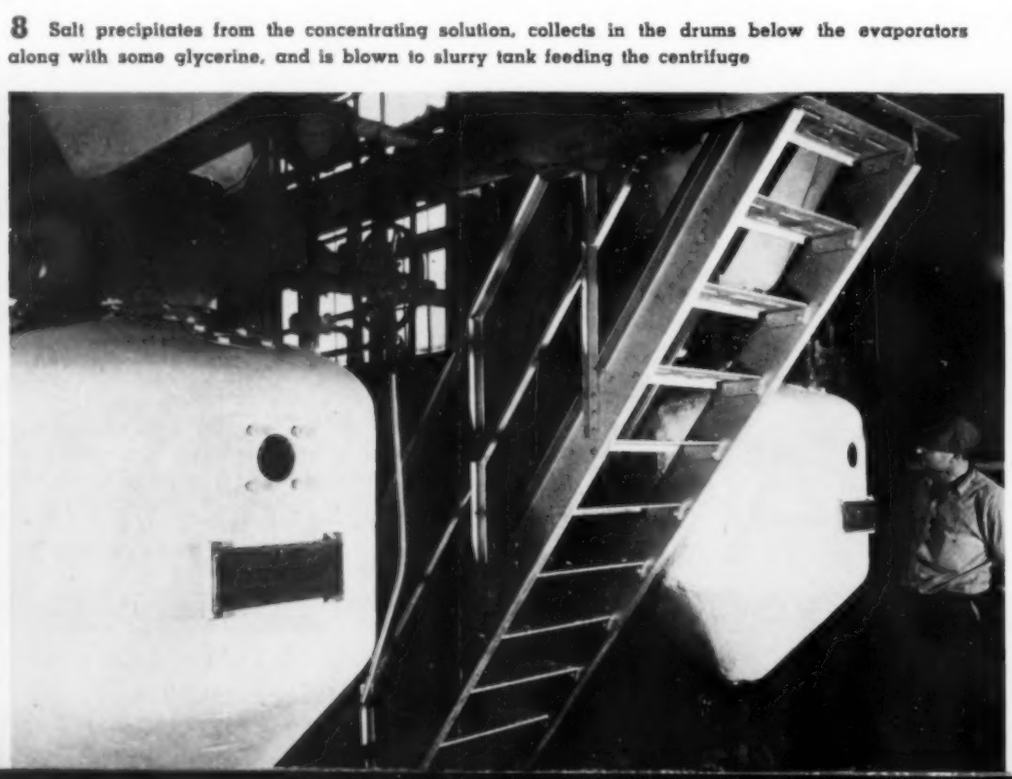
9 The neat soap on leaving the kettle is filtered and then pumped to storage tanks in the packaging building

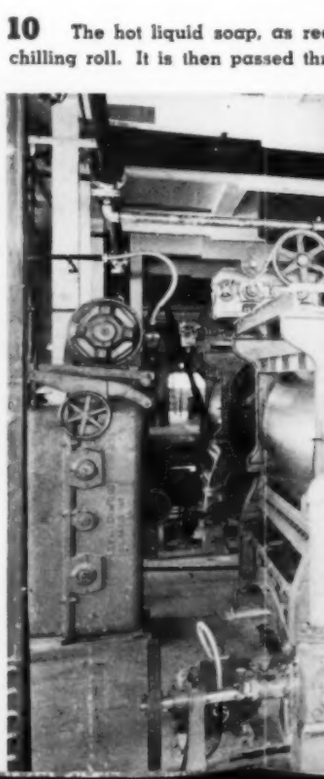
11 On leaving conveyors to any



8 Salt precipitates from the concentrating solution, collects in the drums below the evaporators along with some glycerine, and is blown to slurry tank feeding the centrifuge

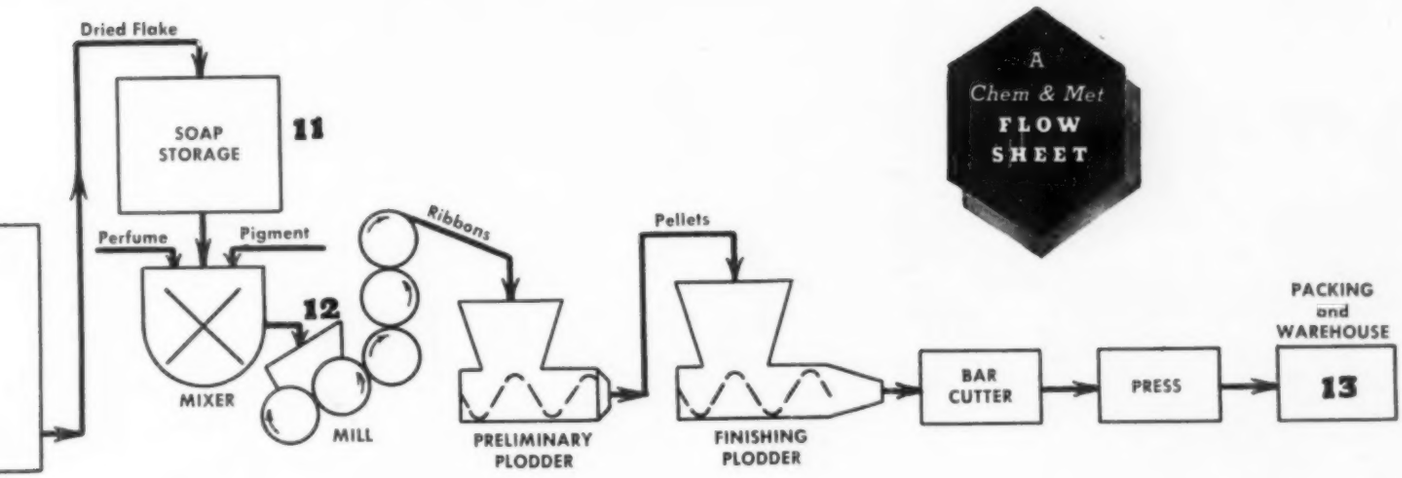
10 The hot liquid soap, as re chilling roll. It is then passed th





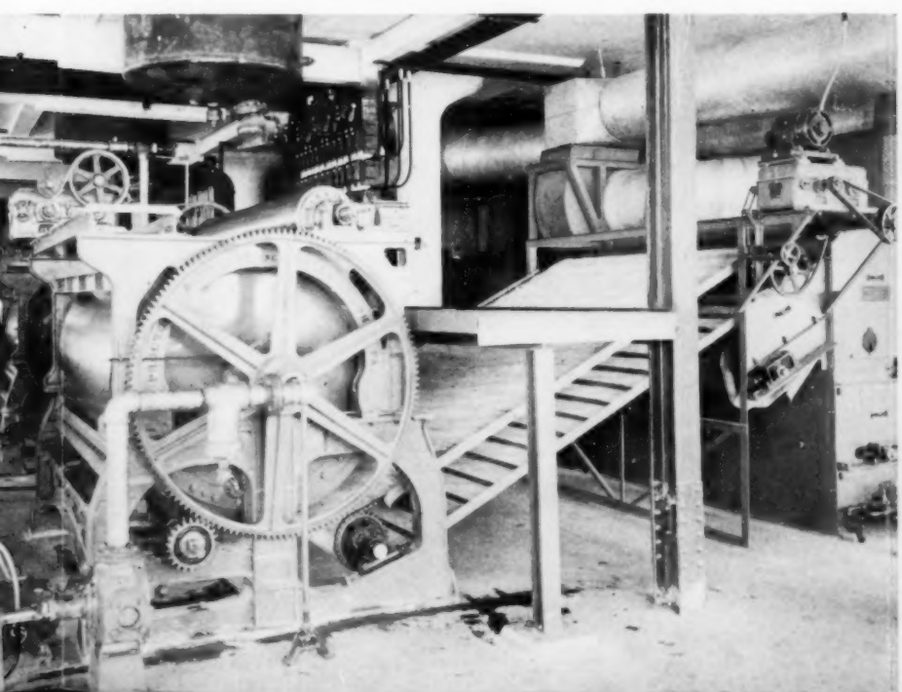
On leaving the dryer the soap is carried by a series of
yors to any one of four bins above the milling machines

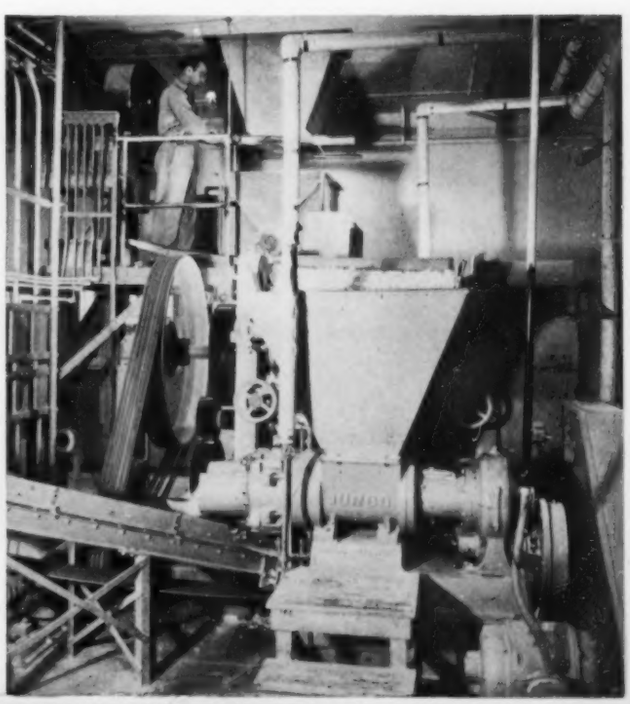
13 Packaging and shipping departments for handling both toilet soap and laundry soap flakes are equipped with modern automatic machinery

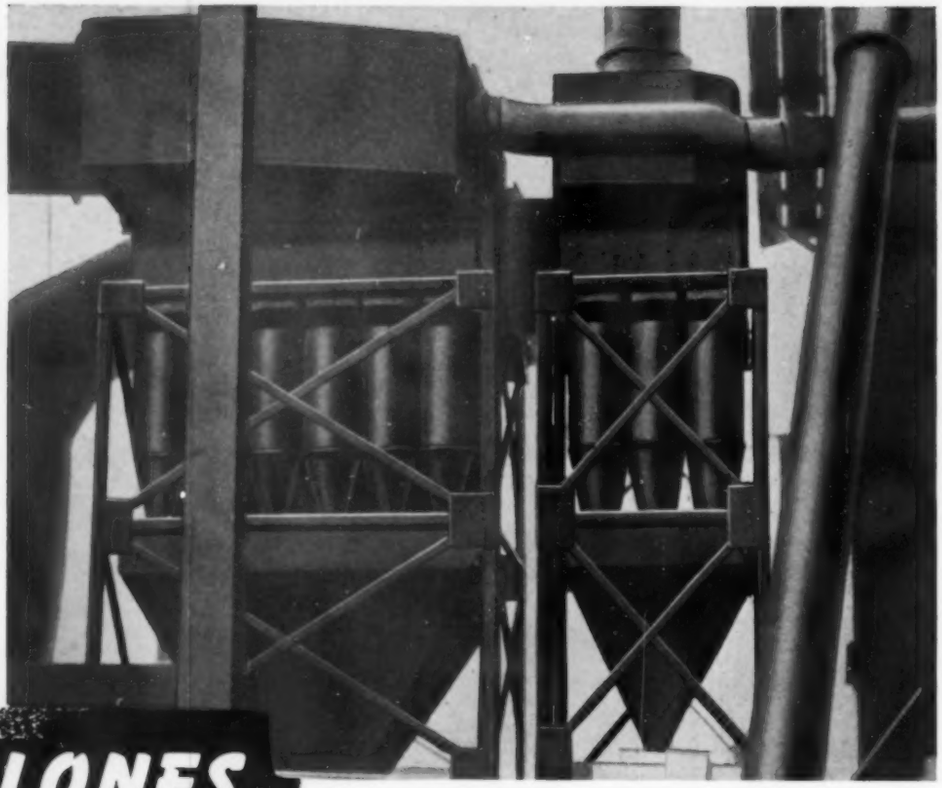


soap, as required, flows into a measuring tank shown at top and from there onto a
en passed through a tunnel dryer in which moisture is reduced to 10 percent

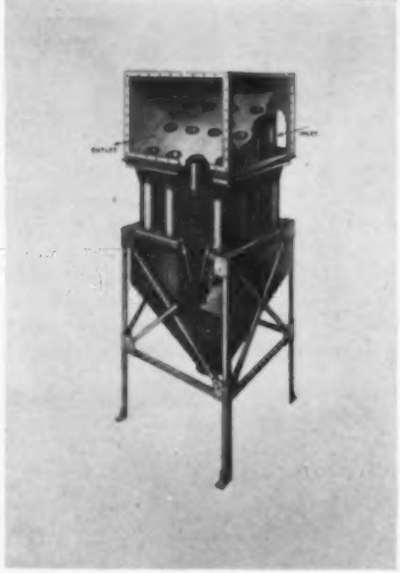
12 Perfume, pigments, and anti-oxidants are added in an amalgamator and the mass blended







MULTICLONES KEEP PACE WITH THE BATTLE OF PRODUCTION



Typical MULTICLONE *Assembly*

With war demands calling for production and *more production*, additional plant capacity is being required. The capacity of MULTICLONE Collectors can be increased by any multiple of the predetermined single tube capacity and efficiency. Additions to present initial installations can be made at any time and to any desired increase. A 50% increase over the original installation is illustrated above.

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PRECIPITATION COMPANY OF CANADA
Dominion Square Building, Montreal

WRITE FOR THIS BULLETIN

MULTICLONE COLLECTORS

. . . THAT PULLING UP A VALVE with the wrench on the unsupported end puts a severe strain on the body—that it may twist the valve and cripple its working parts, cause early leakage of the seats and shorten the life of the valve. Crane "Piping Pointers" showed me the right way—with my wrench on the pipe end of the valve. You get a firmer grip this way; pulling-up is easier with less chance of hurting the valve.

. . . THAT RODDING OUT of viscous and tarry fluid lines can be done easier and faster by installing cross fittings instead of elbows at the 90° turns. You'd be surprised the time it saves on lines requiring frequent cleaning. There's no need to tear them down—you just remove the plugs and work in either direction—another "kink" that helps keep production moving.

...THAT INSTALLING VALVES for easy operation is important in controlling speed and quality of production—to safety of processing equipment as well. You can't expect production workers to open valves fully, regulate them properly, or close them tight, if getting at them is difficult and dangerous. Yet, improper operation quickens wear on valves and often slows production.

HOW TO KEEP YOUR PLANT GOING WITHOUT INTERRUPTION!
11 THINGS YOU CAN DO TO GET BETTER SERVICE FROM PIPING EQUIPMENT
HELPFUL HINTS ON CHOOSING VALVES FOR BETTER PIPING SERVICE
TIPS ON VALVE TRIM

. . . TAKE IT FROM ME, these Crane Shop Bulletins are sound and practical for training new men—for veterans as well! They're full of helpful "kinks" that make piping equipment work better. They're ideal for shop or classroom use. They're genuine aids to Victory and Crane is giving them *free* to any plant or piping man. Just ask your local Crane Representative or write direct to the address below.

CRANE

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VALVES • FITTINGS • PIPE
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DIFFUSIONAL PROCESSES

ABSORPTION, adsorption, crystallization, distillation and rectification, azeotropic separations, extraction . . . "diffusional processes" if you will! For years, Badger Engineering and Construction Service and Badger Equipment have been identified with these processing steps. Years of activity in the "diffusional processes" coupled with activities in other fields of chemical engineering have resulted in an engineering, manufacturing, and construction service of exceptionally broad scope.

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Chemical Engineers and Contractors Specializing in Distillation, Evaporation, Extraction and Solvent Recovery

Technical, Industrial, Personal

CHEM & MET NEWS

DISTILLERIES ORDERED TO MAKE INDUSTRIAL ALCOHOL

Beverage alcohol distilleries must devote 75 days' output of high wines in the remainder of 1942 to meet war requirements for industrial alcohol. This will be in addition to maximum production of 190 proof beverage alcohol by all distilleries having facilities to produce it. The 75-day estimate is based upon current war needs for industrial alcohol and present estimates of maximum high wine capacity of the distilling industry.

Immediate extension of the high wine program, under which 120-140 proof alcohol is shipped to industrial plants for rectifying into 190 proof, is being made by the WPB. Two projects were in operation for the last 10 days of April, one in Kentucky and the other in Maryland. These will be continued and four others operated during May. The new projects will take in distilleries in Pennsylvania, Massachusetts and New Hampshire, and two additional groups in Kentucky. The May program is expected to produce in excess of 1,500,000 gallons of 190 proof alcohol.

DUPONT CHANGES NAME OF R.&H. CHEMICALS DEPARTMENT

Effective June 1. the activities of E. I. duPont de Nemours & Co., carried on under the name of the R. & H. Department will be known as the Electrochemicals Department. The original name arose from the fact that the department was created after the acquisition of The Roessler and Hasslacher Co. in 1930. The new name was chosen because it describes the type of products created by this department without being broad enough to encroach upon the activities of the nine other operating departments of the company. Four plants, operated in New York, New Jersey, Michigan, and California are operated by the new department.

LEADING COMPANIES TO EXHIBIT AT CHICAGO CHEMICAL SHOW

Leading chemical companies of America are to be represented with exhibits at the National Chemical Exposition, which will be held Nov. 17-22 at the Stevens Hotel in Chicago. This became apparent when the show committee of the Chicago Section of the American Chemical Society, sponsor of the exposition, announced that the list of exhibitors already under contract and many who have made space reservations include the names of some of the country's most outstanding firms in the chemical industry.

The importance of the exposition will be enhanced by the National Industrial Chemical Conference to be held in conjunction with noted industrial chemists, educators and manufacturers to be invited to make addresses and lead the discussions. Those who attend the show and conference may participate in this open forum. Marcus W. Hinson is show manager with headquarters at 110 N. Franklin Street, Chicago.

CHEMICAL ENGINEER RESTORES FLAG AT CORREGIDOR

Captain Arthur Elwood Huff, who on May 3 was cited in despatches from the Philippines for bravery under fire of Japanese batteries and dive bombers in the restoration of the American flag to the top of the flagstaff at Corregidor,

Captain Arthur Elwood Huff

is a young chemical engineer from St. Louis. He took the chemical engineering course at Washington University, working nights in the Monsanto laboratories throughout his college career. Later he worked as research scientist in the organic chemical division of Monsanto.

JUNIOR CHEMICAL ENGINEERS WILL MEET ON MAY 25

The Junior Chemical Engineers of New York will hold a meeting at Child's Restaurant, 109 West 42d St. on the evening of May 25. An informal dinner will precede the meeting. W. T. Nichols, chairman of the professional guidance committee of the American Institute of Chemical Engineers and chief of the South Charlestown research division of Westvaco Chlorine Products Corp. will address the meeting and will emphasize the importance of sustained effort to learn during the years following academic training.

ARMOUR RESEARCH FOUNDATION WILL LIST RARE CHEMICALS

Throughout the country's laboratories, schools, and industrial plants are both small and large amounts of uncommon chemicals which have been prepared or obtained for special purposes and not completely used, or which are made for a highly specialized market. The Armour Research Foundation of Chicago has undertaken to act as a clearing house to disseminate information regarding the availability of such chemicals. Requests for file data have been made of some 2,000 industrial and educational laboratories. The file will not be open to general inspection but specific inquiries will be answered. This service which will operate without charge, has been established under the name of the National Registry of Rare Chemicals with Dr. Martin H. Heeren of the Foundation in charge.

COMMITTEE TO STUDY PROBLEM OF ALCOHOL TRANSPORTATION

The legislation that permitted the transportation of high wines to plants with facilities for further distillation together with the movement of industrial alcohol developed some formidable transportation problems while relieving the tension in industrial alcohol supply situation. Solution of these traffic problems is the aim of a Traffic Advisory Committee on Industrial Alcohol, Distilled Spirits and Molasses whose formation was announced late in April by Joseph B. Eastman, Director of Defence Transportation. The committee will act as an advisory body to the War Traffic Section, Division of Traffic Movement.

Ralph R. Luddecke, General Traffic Manager, Fleischmann Distilling Corp., has been named chairman of the committee.

DOMESTIC MATERIALS FURNISH CHARCOAL FOR GAS MASKS

Coconut shells for many years the principal source of charcoal for gas mask canisters and now unavailable in sufficient quantities from its many tropical regions of the war zone no longer presents a shortage problem according to the War Department. The announcement states that ever since the Educational Order Law became effective in 1939 for the experimental manufacture of war material, the Chemical Warfare Service has been working closely with industry to develop pilot plants to produce charcoal from sources of material available in this country. Today many plants are manufacturing this strategic material, using materials which are found here in large quantities.

News from Washington

WASHINGTON NEWS BUREAU, McGRAW-HILL PUBLISHING CO.

SHORTAGE of materials now limits the speed of military effort. Washington talks and argues about working hours, wages, labor supply, profits, and control of the cost of living. None of these, probably not all of them combined, are so serious a limiting factor on how many war goods can be delivered to the fighting front.

This situation compels the severe restriction on the use of metals and machinery. No longer can steel be spared to build plants except in extreme need. Steel, brass, and other metals, all of which are scarce, must go actually into the ships, the tanks, the guns, and the other fighting equipment.

Makeshift chemical engineering is greatly emphasized by this condition. It is necessary to find ways to get a going concern up to greater capacity without providing new structural metal and new machinery. The only exceptions lie in such fields as synthetic rubber for which, of course, it is necessary to build new plants. Chemical engineers in most other fields are going to have to get along as best they can with old, rebuilt, or makeshift equipment and structures.

Patent Seizures

Patents are under fire. Three important factors appear now greatly to decrease the present and the potential value of a patent. These three factors are not entirely separate nor easily distinguished in detail. But it is important to recognize the three separate influences, namely:

1. Seizure of enemy patents was ordered by the President late in April. This puts into the hands of the Alien Property Custodian authority to manage and license these patents for any use during the war, or subsequently, that is in the interest of America. This is purely a war move. It is largely one of convenience because, even before, the Government had a chance under the existing law to use foreign patents whenever necessary for war effort.

2. Patent pooling is being forced. This effort is equally a war measure. The Government wishes to have all parties interested in any particular program, such as magnesium or synthetic rubber, to have access to the best methods and the greatest skills. Only by this means can the maximum progress be made and the minimum patent burden on war effort be insured.

3. Virtual repeal of the patent system is being undertaken, under the guise of patriotic war service. This effort is an anti-monopoly or public ownership effort of zealous crusaders who dress themselves in an Uncle Sam costume in order to ride their hobby. This group grasps at every opportunity to discredit the patent system. They magnify charges of foreign control and claims of interference with the war program. Their purpose, obviously not admitted, is to break down the patent system.

It is difficult to say where one of these three efforts stops and the others begin. There is an over-lapping of activity and a duplication of motives. But the seriousness of the situation in Washington is clearly evident.

The fact that much of this present effort has as its objective the discrediting of the patent system, seems proved by the fact that those backing certain actions are the same ones who during the depression period made an earlier and rather serious attack on patents. It is not sure whether with the stimulus of war-time enthusiasm to help them they can make better progress this time than they did five to eight years ago. In some cases they have the support of high officials which gives substantial significance to their effort.

Trade and Tariffs

Radical change in trade policy is expected as a result of the transfer of import controls to Board of Economic Warfare under Vice-President Wallace. This administrative shift greatly reduces the authority of Secretary of Commerce Jesse Jones and the several operating corporations which have been subsidiary to R.F.C. No longer will that group of government-owned agencies decide what shall be imported, what price shall be paid, or what other import policies shall control rubber, metals, ores, or other wanted commodities.

Under the new policy it is anticipated that much more emphasis will be given to goods controls as an economic weapon. Uncle Sam will now buy not only what he needs for use, but also what he wishes to take away from Axis countries, and what he must buy to support the economy of friendly nations. The pact signed with Peru on April 23 illustrates the extent to which Uncle Sam will go in financing rubber and other developments, even including the purchase of surplus Peruvian cotton. Highway development, extension of mining, agricultural, and other industrial facilities of this Latin neighbor are all provided in this economic warfare arrangement. The fact that Secretary Jones is a member of B.E.W. does not obscure the fact that his influence has waned greatly and that the Wallace-Milo Perkins control is greatly increased.

Also evident during late April is the decision of the Department of State aggressively to push its plan for more tariff cuts through new trade agreements. Several such negotiations were in progress, e.g. with Chile, Uruguay, and Peru. But the scope of activity was tremendously increased by announcement in early April of negotiations with Bolivia and, more importantly, with Mexico. Many important chemical groups of commodities are up for consideration under requested tariff changes or free list freezing. It is expected that the State Department will be rather generous to the Good Neighbor negotiators.

Inflation Controls

The sweeping controls intended by the President for prevention of inflation were presented to Congress on April 27. It was notable that most of the changes in policy described in that message did not require new legislative action. The message was, therefore, in many respects "serving notice" on the Congressmen as to the plans of the President, particularly as he works through O.P.A.

Criticism of the President's proposal was guarded but very real and significant on two points. Many members of Congress were disappointed that they are to be discouraged in their effort to legislate further labor controls. And a substantial percentage of the members of Congress imply that they do not expect a top limit of net income after taxes to be fixed as low as $25,000 per year.

As is inevitable during an election year, the message was both prepared and received as largely a campaign document. The sincerity of the President is not questioned by those who scrutinize the specific suggestions from that point of view. Washington knows that under present circumstances the leading of the people into programs that demand extreme sacrifice is an essential part of this proceeding.

There were seven parts to the President's proposals: (1) Washington expects that the President will be granted profits control legislation. (2) He already has ample authority to fix price ceilings. (3) The argument that wage controls can be handled through War Labor Board action is received with general skepticism. (4) Washington doubts that Congress will consent to cutting agricultural prices back to 100 percent of parity. (5) The pressure for voluntary buying of war bonds is expected to make this item almost as effective as a compulsory program for the vast majority of the public. (6) Rationing is taken for granted; authority exists in O.P.A. (7) Credit control is equally sure to have Congressional support if any loopholes in present law are discovered.

Impartial critics of Washington seem more to fear the development of the pressure groups working through Congressional blocs than they do any general public reluctance to accept all seven of the principles advanced by the President. A slowing of inflationary movement is expected. But any thought that the cost of living can be frozen at present levels does not find many advocates in Washington.

Synthetic Rubber

The synthetic rubber production goal was increased again late in April, as

the War Production Board promised all necessary priority assistance for construction of facilities for an annual productive capacity of 700,000 tons of Buna S by the end of 1943. This is in addition to plant capacity for a total of 100,000 tons of Butyl synthetic and neoprene.

In addition to accepting the end of 1943 as the deadline for completing the total program, WPB stated that construction would be scheduled so that actual production of Buna S in 1943 would amount to 350,000 tons. This, the statement made clear, provides no synthetic rubber for civilian tires prior to 1944.

Rubber Reserve Co. has concluded arrangements with the Government of Peru for the establishment of a fund of $1,125,000 to be used by the Peruvian Amazon Corp., a governmental agency, to increase wild rubber production in that country. Rubber Reserve will purchase the entire output for five years, except that required for essential uses in Peru, as an offset against the fund.

Chemical Miscellany

New Scarcities—Occasionally W.P.B. issues lists to show the relative scarcity of materials. These are short-lived in usefulness except as a general guide for planning. Almost every kind of material that has any important industrial application finds also military uses. Scarcities follow automatically. For example, all of the dyes suitable for uniform cloth manufacture are being held exclusively for that usage. Even certain ink raw materials are restricted by allocation. It is not far from the truth to assume in May that complete chemical allocation is not very distant for any chemical of wide application and is certain for anything of definite military usefulness.

Data Withheld—The Bureau of Internal Revenue of the Treasury Department no longer gives out statistics on industrial alcohol or distilled beverage production. These figures have assumed military significance because of the requirements for alcohol in the war program.

Chemical Manpower—Civil Service Commission estimates indicate a serious shortage of chemical engineers for the government service. Those willing to take government appointments should make application to Civil Service Commission, Washington, D. C., for blanks permitting a non-assembled examination (mere filling out of form with references). Salaries range from $2600 to $4600 per year on vacancies now open.

New Tin Plate—Washington is delighted with the aggressive plan of U. S. Steel Corp. to make extensive development of electrolytic processes for tin plate manufacture. The new program contemplates making 9 million base boxes (450,000 tons of tin plate) by this method using only 2,250 tons of tin. This represents a saving of 60 percent of the scarce metal which would have been used by the old style hot dip process. Despite this effective development, scarcity of tin plate is certain for all uses, even food packaging.

Alcohol Program—Adequacy of alcohol supply this Spring is not blinding W.P.B. executives to the urgent need for more alcohol later. As the synthetic rubber program develops, it is almost unbelievable that too much alcohol can be provided. Those who can supply fermentable materials from domestic sources as molasses substitute are always welcomed at the Chemical Branch of W.P.B.

Magnesium Quarrel—Despite very satisfactory progress on most phases of the magnesium program, there has been a bitter controversy between Senator Bunker of Nevada and R.F.C. Boss Jesse Jones regarding plans for making magnesium from dolomite in Nevada. Washington does not take this political mudslinging too seriously, despite charges of "malfeasance", "fraud", and "sinister" proceedings. Official Washington does worry, however, about the long time which it takes to build the huge and complicated magnesium works.

Rubber Program—Very broad powers to direct and coordinate all phases of the synthetic rubber program have been granted to Arthur B. Newhall as coordinator in W.P.B. It is expected that in this office there will be sufficient authority to prevent conflicting projects from interfering with each other or slowing down actual production either of rubber chemicals or the synthetic rubber itself.

Plenty of Mercury—To prevent surplus mercury from glutting the spot market, it is arranged that Metals Reserve Co. will buy this extra domestic output at $192 per flask f.o.b. New York. Without this prompt market there was fear that the small producers working on a narrow financial margin might slow down production. Official Washington has no fear that there will be any permanent surplus requiring subsidy.

Silver Busbars—About 35 percent of the tremendous reserve of silver held by the Treasury Department is to be cast into busbars and used as conductors in aluminum reduction plants, or other electrochemical works. The object is to save copper. Since most of these lines will be "hot' at all times, no one worries much about theft. In any event, casual visitors are not expected in these defense plants.

Plant Protection Schools—There are being organized plant protection schools to train personnel of industries, especially those in coastal states, regarding means of minimizing plant damage during enemy action. Those interested

Domestic Tungsten—The domestic production of tungsten at small mining enterprise and at high cost mines is to be stimulated by a new set of contracts. Metals Reserve Co. promises to buy tungsten concentrate at the price of $24 per dry short ton unit of WO_3 under conditions and with bonus or penalty provisions provided in an elaborate schedule. Small producers who cannot make concentrate may ship their low-grade ore to a government-owned beneficiation plant. Thus, they too may share in the bonus for domestic output.

NEW PROCESS FOR TREATMENT OF CHROME ORES

A process for obtaining up to 99.8 percent pure chromium metal in a sponge or powdered form is announced by the Bureau of Mines as ready for pilot plant scale operation. The process uses either high or low grade ores as a raw material.

Chief difficulty of utilization of the process now is that it requires relatively large amounts of chlorine. Basis for the process is a low temperature reduction without sintering. Chromite ores are chlorinated at elevated temperature, the volatile chlorides drawn off and the chromium metal produced by hydrogen reduction.

Methods and formulas employed in the five years of laboratory production of sponge chromium are described in a technical bulletin—"Sponge Chromium" by C. G. Maier (No. 436)—available from the Superintendent of Documents.

REVISED LISTING OF CORROSION TECHNOLOGISTS CONTEMPLATED

The American Coordinating Committee on Corrosion is contemplating revision of its confidential directory of technologists actively engaged in studies on corrosion and its prevention. The committee comprises delegates from the seventeen major technical societies together with representatives from the principal industrial research institutes and the National Bureau of Standards. Its directory currently lists some 400 investigators in a diversity of corrosion-preventive fields, selected on the basis of questionnaires circulated to the membership of the committee's member societies. While it is felt that the directory list is quite complete, there are undoubtedly some individuals who were not reached during the original circularization. Accordingly, the committee now requests that all persons actively engaged in corrosion researches who have not been contracted, write to the secretary, Dr. G. H. Young, 4400 Fifth Ave., Pittsburgh, Pa. for further details and application forms for directory listing.

MONSANTO IN PRODUCTION AT NEW TRENTON PLANT

Monsanto Chemical Co. began production at its new plant in Trenton, Mich., on April 28. The plant eventually will manufacture a group of industrial chemicals derived from phosphorus which material will be supplied from the company's electric furnace plant at Monsanto, Tenn. The new plant occupies a tract of 138 acres and consists of a number of manufacturing and service buildings as well office building. It has its own dockage facilities on the Trenton channel of the Detroit River as well as belt line rail connections with all major transportation systems.

MATERIALS IN SCARCE SUPPLY LISTED IN RELATED GROUPS

The second in the series of provisional reports on the relative scarcity of certain materials, prepared by the Conservation and Substitution Branch of the Bureau of Industrial Conservation, was made public last month. Group 1 is made up of materials that generally are critically essential for the prosecution of the war. For these materials, civilian industry must largely find substitutions or anticipate stoppage of manufacture of articles containing them. Chemicals derived from scarce metals are, in general, of the same order of scarcity as the metals.

GROUP I

Materials Most Vitally Needed for War Purposes: Not Generally Available for Civilian Needs

METALS

Alloy steel
Aluminum
Aluminum scrap
Cadmium
Calcium-silicon
Chromium
Cobalt
Copper
Copper scrap
Iridium
Iron alloys
Magnesium
Nickel
Nickel scrap
Rhodium
Tin
Tinplate and terneplate
Tungsten and carbides
Vanadium
Wrought iron
Zinc, high grade

CHEMICALS

Acetone
Alcohol, methyl
Ammonia, anhydrous
Anthroquinone derivatives
Chlorinated hydrocarbon solvents
Chlorine
Diphenylamine
Formaldehyde
Halogenated hydrocarbon refrigerants
Methyl methacrylate
Phenol formaldehyde resins and plastics
Phenol
Phosphates:
Tricresyl
Triphenyl
Phthalic anhydride and phthlates
Polystyrene
Polyvinyl chloride
Sodium nitrate, pure
Toluol
Urea formaldehyde plastic

MISCELLANEOUS PRODUCTS

Agar
Asbestos, long fiber
Burlap
Cashew nut shell oil
Corundum
Cotton linters
Cotton duck
Feathers and down
Graphite
Hemp
Jewel bearings
Kapok
Kyanite
Mica splittings
Nylon
Palm oil
Pig and hog bristles
Quartz crystals
Quinine
Rape seed oil
Rubber
Shearlings
Shellacs
Silk
Sperm oil
Teak
Tung oil

GROUP II

Basic Materials that are Essential to the War Industries but Whose Supply is not as Critically Limited as Materials of Group I.

Albumin, blood
Alcohol, ethyl
Antimony
Arsenic
Barium carbonate
Benzine
Beryllium-copper
Borax, boric acid
Butanol
Calcium
Camphor
Carbon tetrachloride
Citric acid
Cocoanut oil
Cork
Cotton
Cotton seed
Cryolite
Diamonds
Ferrosilicon
Flax
Fish liver oils
Glassine papers
Glues
Glycerine
Glycols
Henequen
Hides
Jute
Kraft paper
Lead
Leather
Lithium
Manganese
Mercury
Methyl methacrylate
Powder
Molasses
Molybdenum
Natural gas
Natural resins, except rosin
Parchment paper
Phosphorus
Pig iron and scrap
Platinum
Potassium perchlorate permanganate
Quinine
Rayon
Rubber, reclaimed
Ruthenium
Silicon and alloys
Sisal
Steel, scrap
Spirits, distilled
Steatite talc
Tanning materials
Tetraethyl lead
Titanium pigments
Vitamin "A" products
Vulcanized fiber
Wood pulp
Wool
Xylol
Zinc (low grades)
Zirconium

GROUP III

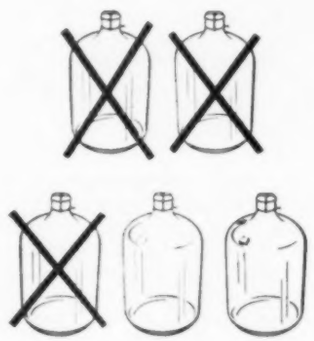
Materials available in significant quantities for other than strictly war purposes. However, the use may be restricted by accompanying manufacturing limitations. Restrictions are commonly imposed but supplies are not critically short, except in the case of iron and steel.

Preferred Substitute Materials:

Asbestos, common
Asphalt
Brick and tile
Carbon black
Casein
Cement
Ceramics
Charcoal
Clay
Coal and coke
Coal tar pitch
Concrete
Cotton, raw
Diatomite
Emery
Feldspar
Gilsonite
Glass
Ammonia, aqueous
Atebrine
Bismuth
Cellophane
Cottonseed oil
Fluorspar
Hair; cow, horse
Invert sugar
Iodine
Iron, gray cast
Iron, malleable
Lactic acid and lactates
Linseed oil
Gold
Gypsum
Indium
Lignin plastic
Lime
Lumber
Mica, common
Mineral wool
Muriatic acid
Osmium
Paper
Paperboard
Plywood
Pottery
Salt
Silica sand
Palladium
Petroleum products
Plastics:
cellulose acetate
butyrate
Rosin and derivatives
Silver
Starch
Stone:
granite
limestone
marble slate
Straw
Sulphur
Tripoli
Vermiculite
Wall board
Wood, sawdust, wood fibers, wood flour
Sodium metasilicate
Sodium nitrate
Soy beans protein oil
Steel
Sugar
Turpentine
Uranium

3 out of 5 raw materials unavailable... yet delivery was made on schedule!

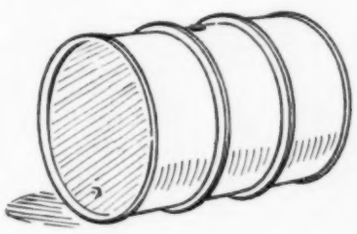
One of a series of cases from the files of Monsanto's Technical Service Department which show how skill, experience and ingenuity can solve many critical wartime problems. For obvious reasons identifying names and any clue have been omitted.



1. The order read—"Must have delivery in three weeks!" or work will stop on a vital construction job!

But of five chemical raw materials required to manufacture the particular product called for —*three had been drafted for defense!*

There seemed nothing else to do but write the customer, "Sorry! We can't supply etc., etc." Certainly such a letter is no novelty these priority-troubled days.



2. Monsanto sales correspondents, however, are often deliberately *slow* on the trigger.

Before the sales department mailed its regrets, they put Monsanto's able Technical Service Department to work on the problem.

In the specified three weeks, adequate replacements for all three unavailable materials had been found and thoroughly tested—*and the order was in the customer's receiving room!*

3. Obviously not all the problems created by the present emergency can be so quickly and happily solved. But two factors often give Monsanto technical men an invaluable head start toward a solution... a thorough understanding of *your* problems and basic processes...and, equally important, a broad knowledge of their *own* business which springs from the very breadth and variety of Monsanto's chemical manufacturing experience.

UNIFORMITY—STILL AN ESSENTIAL

No matter how great the pressure for more and more production, in nearly every chemical used by industry, in war as in peace, *uniform* quality is still essential in *every* shipment.

That's why *every* batch of *every* Monsanto chemical, in wartime as in peacetime, is carefully controlled at *every* step in its manufacture...and *every* batch is *double-checked* in the control laboratory before it leaves Monsanto's plant for yours. MONSANTO CHEMICAL COMPANY, St. Louis, U. S. A.

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BRITISH CHEMICAL ENGINEERS LAUNCH CAMPAIGN TO INCREASE FUEL EFFICIENCY

Special Correspondence

IMPROVED fuel efficiency is the aim of a campaign which has been launched by the British authorities and warmly taken up by fuel engineers in the chemical industries. Economy in the use of coal is one object of the drive, application of the most suitable types of coal and coal derivatives is another, and research workers cooperate in endeavors for the development of new outlets for neglected byproducts of coal processing and improvement of plant equipment. The following examples may help to indicate the recent trend:

The Gas Research Board has had under consideration the possible production at gasworks of coke activated by addition of alkalis, suitable as a fuel for ordinary open domestic grates. It was found that it is not necessary to mix the alkali with the coal before carbonization in order to prepare alkali-activated coke; the coke can be activated by impregnation after leaving the retort. In order to obtain the most reactive coke it is necessary to select from within a specified range the class of coal to be carbonized, and to carbonize it under controlled conditions in continuous vertical retorts.

The United Kingdom Coal Products Ltd. has evolved a method for using tar as a raw material in vertical retorts in gasworks. A big plant has been converted to the system, while other gasworks are expected to avail themselves of this process for increased production of benzol hydro-carbons and gas with a minimum formation of coke. Previous attempts to make use of tar for gas making have failed, mostly because the extent of decomposition of the tar was either too great or too little and because carbon was found to build up in the retort. Details of the new method are withheld but the process is known to be a modification of an American process for cracking petroleum oils in continuous vertical retorts carbonizing coal for town gas production. The capital outlay in installing the new system is estimated at no more than £30 per retort.

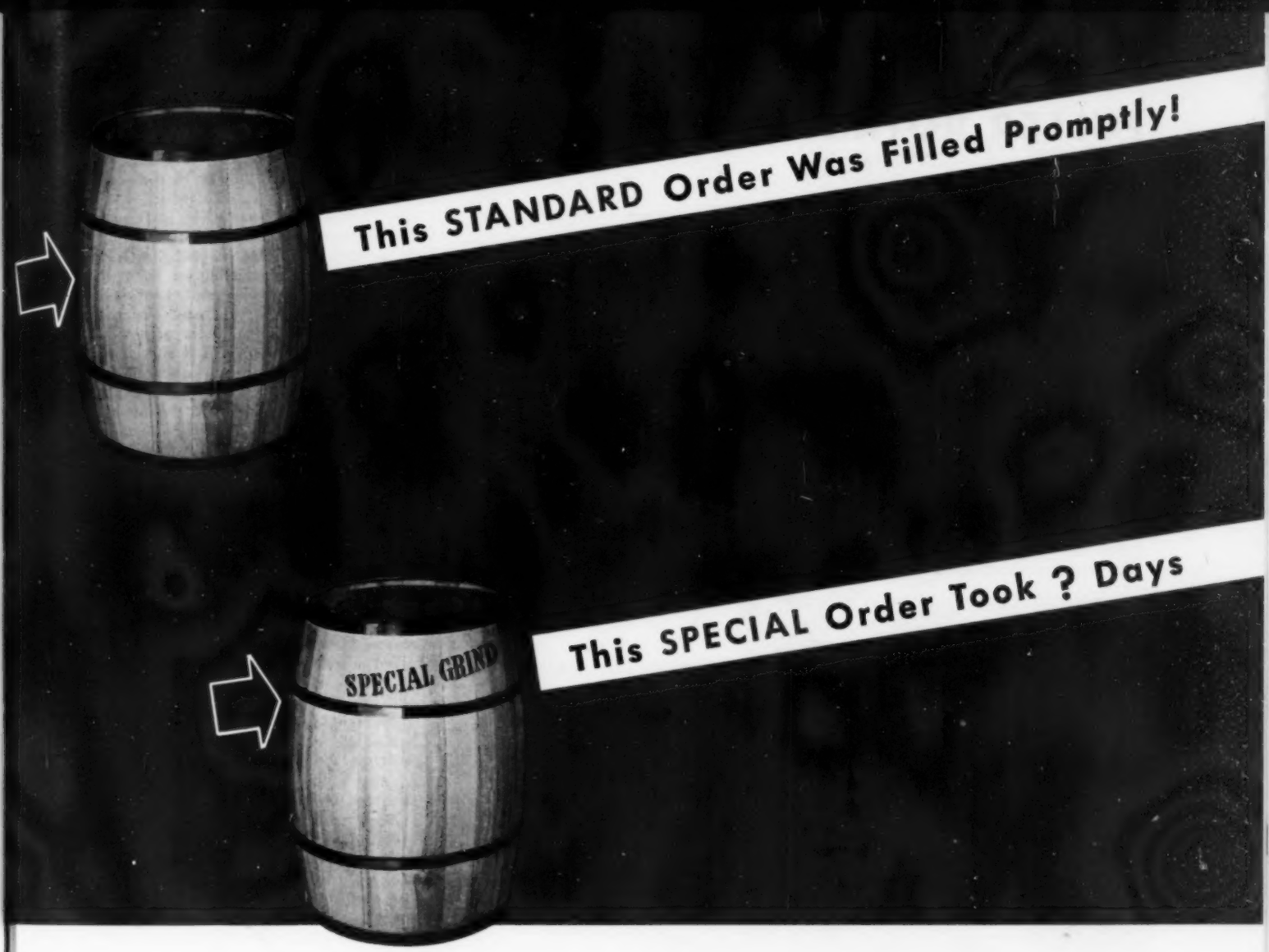
Laboratory experiments on the partial or complete gasification of coal in hydrogen under pressure have reached a stage where a semi-industrial plant can soon be erected. The reaction vessel and ancillary plant will be built at a convenient site where the requisite facilities are available, and a special sub-committee has been formed by the Gas Research Board to make recommendations concerning the large-scale investigation of hydrogenation and complete gasification. In essence the process developed on a laboratory scale involves the enrichment of water gas by means of methane produced in the reaction vessel under appropriate operating conditions, assisted if necessary by catalytic synthesis of methane from the reaction gases.

A new outlet for surplus coke may soon be developed. Cokes having sufficient reactivity to be suitable as fuel for portable gas producers can be made from a variety of coals in commercial gas retorts. The processes available for this purpose will require additional supplies of coal if the present supply of town gas from the works in question is not to be reduced. The magnitude of such additional supplies depends upon the particular process adopted, but it is clear that all these new developments can be pursued successfully only insofar as byproducts of the coal derivatives concerned can be disposed of. In the examples quoted the object in view seems to be an increase in supply of liquid hydro-carbons accompanied possibly by a larger output of gas, while the production of solid materials like coke and tar is, if possible, to be reduced. Evidence of the increased call for liquid products from gasworks and coke ovens was provided by the order extending control to coal-tar naphtha and xylol.

A very important extension of government control in chemical industry will take place when the fertilizer rationing scheme now under preparation in the Ministry of Agriculture comes into operation. It will deal with potassic, phosphatic and compound fertilizers. Farmers will receive coupons entitling them to purchase definite quantities of the respective fertilizers. The quantities will be based on the 1943 cropping programs as approved by the authorities. The acreage devoted to various crops will determine the number of coupons to which a farmer is entitled. Experimental rationing schemes are already in operation in the important farm district of Norfolk and East Sussex and provide the basis for a nation-wide scheme. The distribution of the fertilizers is to be left in the usual hands.

The Ministry of Agriculture is likely to interfere also in another important section of the chemical trades. It is considering now a plan for manufacturers of proprietary brands of insecticides and fungicides to put their products on an approved list. Many brands containing lead arsenate, lime-sulphur, and tar-oil washes are made in accordance with specifications approved by the Ministry of Agriculture and will be placed on the list automatically. Where no specifications exist, manufacturers will be asked to disclose, in confidence, particulars to substantiate their claims so that the authorities can form an opinion of the value of these products. The approved list will give consumers an assurance regarding the quality of their supplies and help manufacturers to extend their markets. The proposed measure is typical of the tendency of standardization and quality control in the country.

In order to reduce the demand for



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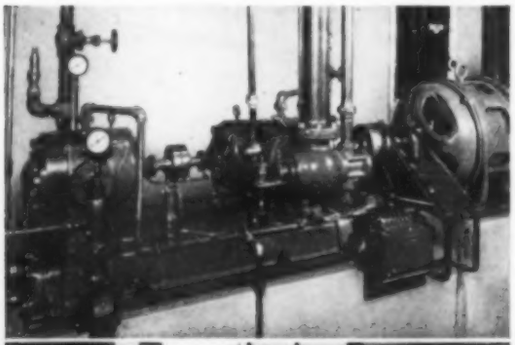

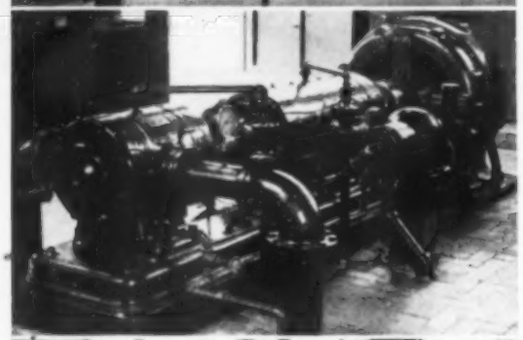

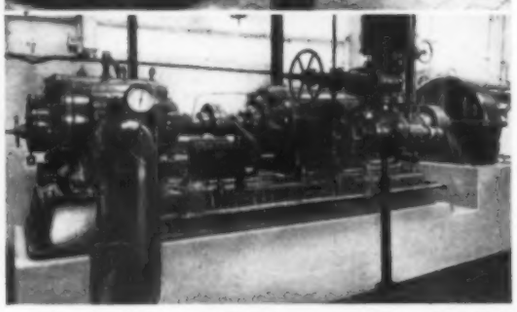

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PIONEERS OF HIGH-EFFICIENCY ROTARY COMPRESSORS

shipping space for bauxite from overseas sources needed in growing quantities for the manufacture of aluminum, the Imperial Institute has carried out experiments on the calcination of bauxite. It was found that under optimum conditions a reduction of weight by 25 percent could be effected in Gold Coast bauxite by calcination at 400° C while leaving the material still amenable to the Bayer process for the extraction of alumina by caustic soda solution under pressure. The solubility of the alumina was not appreciably lessened.

British paint makers are paying attention to dehydrated castor oil as a substitute for tung oil. With the new type of barium carbonate extended titanium pigments—8 lb. to the gallon—quick-drying, tack-free, non-yellowing paints of high performance have been obtained with the 46 poise type, and if the higher viscosity oil is used, flat paints may be made carrying much more pigment. Experiments with a 3:1 linseed-dehydrated castor oil pigmented with titanium pigments have given a performance very similar to a corresponding tung oil mixture. If 120 and 180 poise oil is used, up to 10 percent of zinc or calcium rosinate are added. Small amounts of melamine resin (about 3.5 percent) were found to speed up the rate of polymerization and of drying.

Vinyl compounds are finding increasing use in British electro-plating works since it has been found that their use as throwing agents results in greater uniformity of the metal deposit at various distances from the anode than is obtained with glue, dextrine, gum arabic, peptone and other substances. Besides they permit continuous platings of exceedingly thin layers of various alloy metals which are now in limited supply. Electroplating as a means of saving strategic metals is bound to increase in importance, and it is considered likely that the use of synthetic reagents will increase much further.

Among new glass substitutes offered in the English market is a cellulose acetone product which achieves rigidity by means of a corrugated face applied to a smooth backing. It is weatherproof, pre-shrunk in manufacture, and does not require varnishing. It gives a high degree of insulation and allows ultraviolet light to pass. Compared with other materials used to replace sheet glass in bombed buildings its cost is rather high, but its advantages are so obvious that it is likely to be used on a fair scale.

In view of the increasing difficulty of obtaining gums from abroad attention is being paid to sodium alginate, now included in the National War Formulary, as a substitute for tragacanth, etc. It is prepared by macerating seaweed in water and boiling the insoluble residue in sodium carbonate solution. The dissolved sodium alginate is purified by precipitation with hydrochloric acid, redissolved in soda and evaporated on glass plates. An

emulsion according to the British Pharmacopœia formula for Emuls.-Paraff. c.Agar in which the agar and tragacanth content were replaced by an equal weight of sodium alginate proved in all respects equal to the original. Smaller amounts also gave satisfactory results, especially in conjunction with smaller quantities of acacia gum. There are various other possibilities for economies and new applications.

The British Government has taken an active financial interest in the manufacture of synthetic vitamins by the formation under the auspices of the Ministry of Food of a new company—Flour (Accessory Factors) Ltd.—to undertake commercial and industrial activities in connection with the production of aneurin (synthetic vitamin B-1) and its introduction into white flour. The extra cost of Canadian flour which is fortified for British use by admixture of synthetic vitamin from Canadian manufacturers is approximately 10 pence per sack of 280 lb. and it may be assumed that the cost of the English synthetic vitamin is similarly low. The practical significance of the new production has been reduced, however, by the government decision to insist on a standard flour of greater extraction. As the white flour (of 75 percent extraction) will soon disappear from the British market, there is no demand for the synthetic vitamin B-1 unless it should be decided to use it for other foodstuffs.

The importance of correct surface preparation for steelwork protection by painting is stressed by the Corrosion Committee of the Iron and Steel Institute. Some advantage attaches to the Duplex process of pickling in which the steelwork is rinsed in water after descaling in sulphuric acid and then dipped in dilute phosphoric acid containing iron phosphates.

ALLIED CHEMICAL & DYE CORP. CONTINUES FELLOWSHIPS

Allied Chemical & Dye Corp. has announced continuation of its graduate fellowship plan in the academic year 1942–43. The recipients of the fellowships and the subjects are chosen by the universities; subjects are not restricted to those connected with the products or interests of Allied's operating divisions and subsidiaries. Stipend of each fellowship is $750.

The universities and colleges to which awards have been made for 1942–43 are: University of California, California Institute of Technology, Columbia University, Cornell University, Harvard University, University of Illinois, The State University of Iowa, Massachusetts Institute of Technology, University of Michigan, University of Minnesota, Northwestern University, Ohio State University, University of Pennsylvania, Pennsylvania State College, Princeton University, Purdue University, University of Wisconsin, Yale University.

PROTECTION AGAINST PROFIT LEAKS

Many a manufacturer, after adopting Bemis Waterproof Bags, has found the answer to costly, annoying profit leaks. Replacements and allowances for loss of quality and quantity in transit and storage—loss of customers through dissatisfaction—these and many other profit leaks have been overcome by shipping in Bemis Waterproof Bags.

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Only HARD RUBBER will do!

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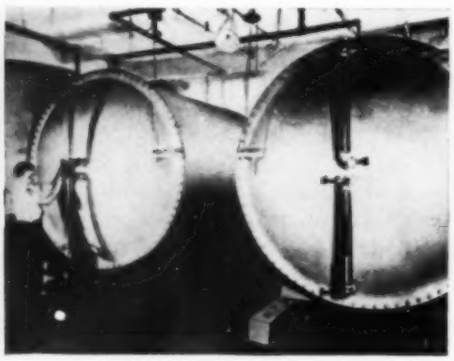
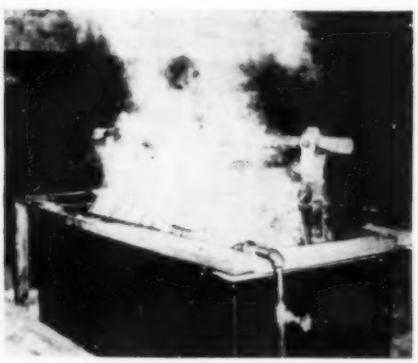


Ace rubber lined storage tanks in any capacity for safety of chemicals.

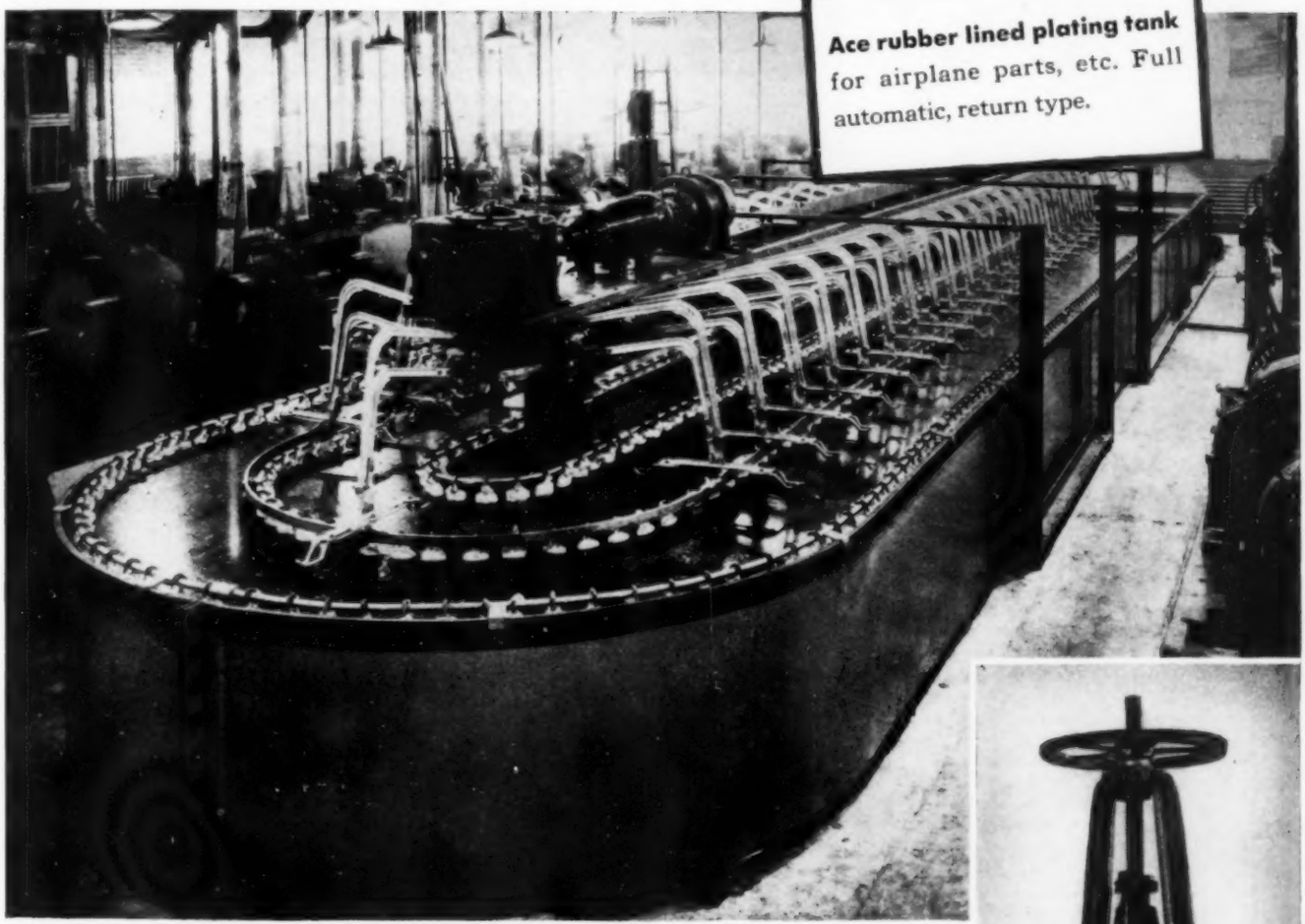


Ace rubber lined pickling tanks are engineered for service.

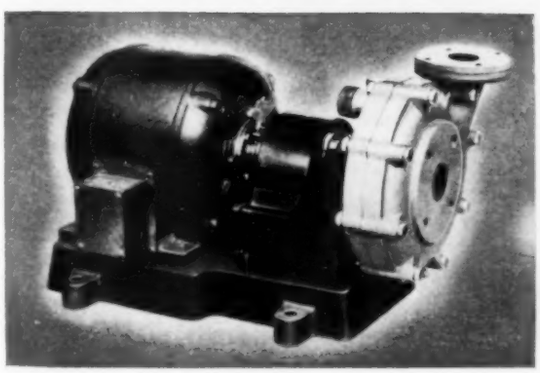
ACE

AMERICAN HARD RUBBER COMPANY, 11 MERCER STREET, NEW YORK, N. Y.

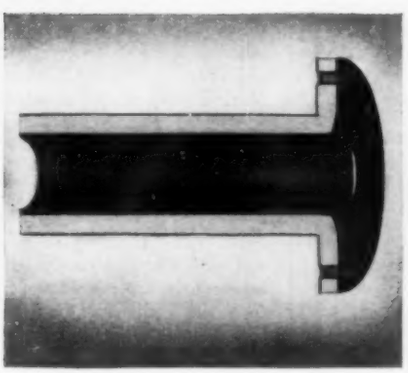
★ ★ ★ ★ ★ ★ ★ ★ ★ ★ ★ ★ ★ ★



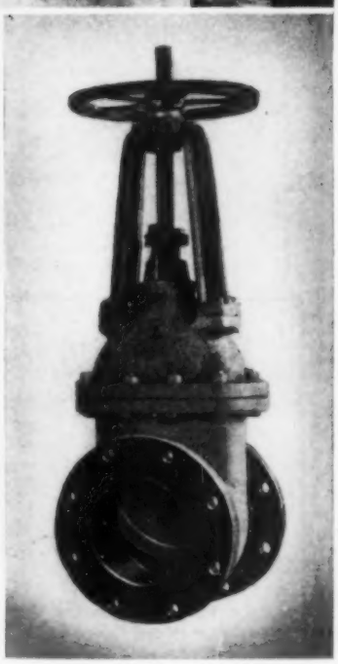
Ace rubber lined plating tank for airplane parts, etc. Full automatic, return type.



W.A.M. hard rubber Centrifugal Pump. Simplified design. Economical in price—Economical to operate—Economical to maintain. Also Single Acting, Double Acting and Rotary Gear pumps.



Ace rubber lined steel Pipe. Sizes 2 inch up. New lining technique for pipe, fittings and valves makes ends free of restriction.



Ace hard rubber lined Gate Valve. Flanged type with outside yoke and stem. Sizes 2 in. to 20 in. (except 2½, 3½ and 5 in.).

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WESTERN POLAND INDUSTRIES NOW FULLY INTEGRATED INTO NAZI CONTINENTAL STRUCTURE

Special Correspondence

EDITOR'S NOTE: *Cut off from direct correspondence with all except a few foreign sources in neutral countries, these notes interpret recent developments in continental Europe as reported in publications and official documents received in the United States. These monthly letters, prepared in this country, will be continued only so long as pertinent material of interest to American chemical industry is available for our comment and interpretation.*

LYING as a buffer between Germany and the U.S.S.R. and astride the Nazi lines of communication and supply to the central and southern Russian front are important industries of the former Polish Republic. Little publicized at present, these industries, seized almost intact because of the swiftness of the Polish campaign, are operating largely for the German war machine and are involuntarily backing up the Reich's eastern battlefronts.

With the partition of Poland at the end of 1939, the U.S.S.R. got most of the petroleum producing regions of the southeast of the Republic, while Germany got the western coal and zinc and general manufacturing areas. When Germany attacked the Soviet Union in the summer of 1941, the Russians withdrew from eastern Poland, presumably not without destroying or removing equipment and stores, so that capture of this area so far has not added much to German oil supplies. From reports reaching here, it is evident that the western areas, however, are now fully integrated in the Nazi continental industrial structure.

Former Polish state-owned factories are now part of the "Werke des General gouvernements A.G.," administered by the huge Hermann Goering concern. Other Polish factories have been taken over by large Reich firms, some of which already had a financial interest in Polish enterprises even before the outbreak of the war, and in some cases negotiations for buying out foreign-owned companies have been carried out by neutral nationals, presumably for the account of the Reich. Poland's heavy industries, based on domestically available raw materials, coal, wood, salts, ores, and petroleum are centered in the two industrial triangles, one in Upper Silesia, directly adjoining the former German frontier, and the other in the new partly-finished Sandomierz project in the interior of Poland. Finishing industries producing textiles, pharmaceuticals, etc., are located around larger Polish cities such as Warsaw, Cracow, Lodz (renamed Litzmannstadt after the early Nazi general), Lemberg, and Danzig, Posen, and Thorn of the former Corridor area.

Of 45 smaller pharmaceutical plants located in western Poland, 32 are located in Warsaw and the remainder in Cracow, Czenstochowa, Kielce, and Radom. For war purposes, the two most important Polish chemical enterprises, supplying both nitrates and fertilizers and essential chemicals, are the large modern former state-owned plant at Chorzow in Upper Silesia and the former Moscice plant (named after the ex-president of Poland) near Tarnow in the second Galician industrial area. Supplementing these factories are several synthetic rubber, synthetic fiber, and cellulose and wood-processing plants, utilizing the vast forest resources of Poland.

To what extent the Germans can consolidate industrial gains in southern Russia depends entirely on current military operations. Last fall when the Reich was still optimistically expecting an early victory over the U.S.S.R., Alfred Rosenberg was appointed Reich Minister for Occupied Russian Territory, which then included an area three times the size of pre-war Germany and comprising a population of 75 million people. He set up many bureaus and had engineers take stock of industrial properties and plan resumption of work in mines and factories, some of which were not demolished by retreating Russians. Former Russian government-owned industries were taken over either directly for operation by the Reich, while some were turned over to private interests. The Ost-Oel Co., organized to handle Caucasus oil in the event that the Germans would take the Grozny and Baku areas failed to fulfill its large-scale plans because these regions were not captured.

In the meantime, Russians have tried to build up reserve supplies. That research activities have continued despite war operations in the U.S.S.R. is indicated in the scientific journals reaching this country and by the increased number of Russian works referred to in Chemical Abstracts. A recent minor development of possible interest to the United States is the production of phonograph records in the U.S.S.R. without the use of shellac, much of which in peace times was imported from India. According to the Mendelejeff Chemical-Technical Institute an aqueous solution of polyvinyl chloride is being substituted for shellac in the manufacture of the phonograph discs. The Russian Institute for Epidermology and Microbiology reports that it is now undertaking production of vitamin C extracts from wine grape leaves in Armenia. In experiments it is claimed that the vitamin C content in grape leaves was found to be three to four times that of lemons and ten times that of cabbage.

To hasten seasoning of lumber elec-

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CLOSURES

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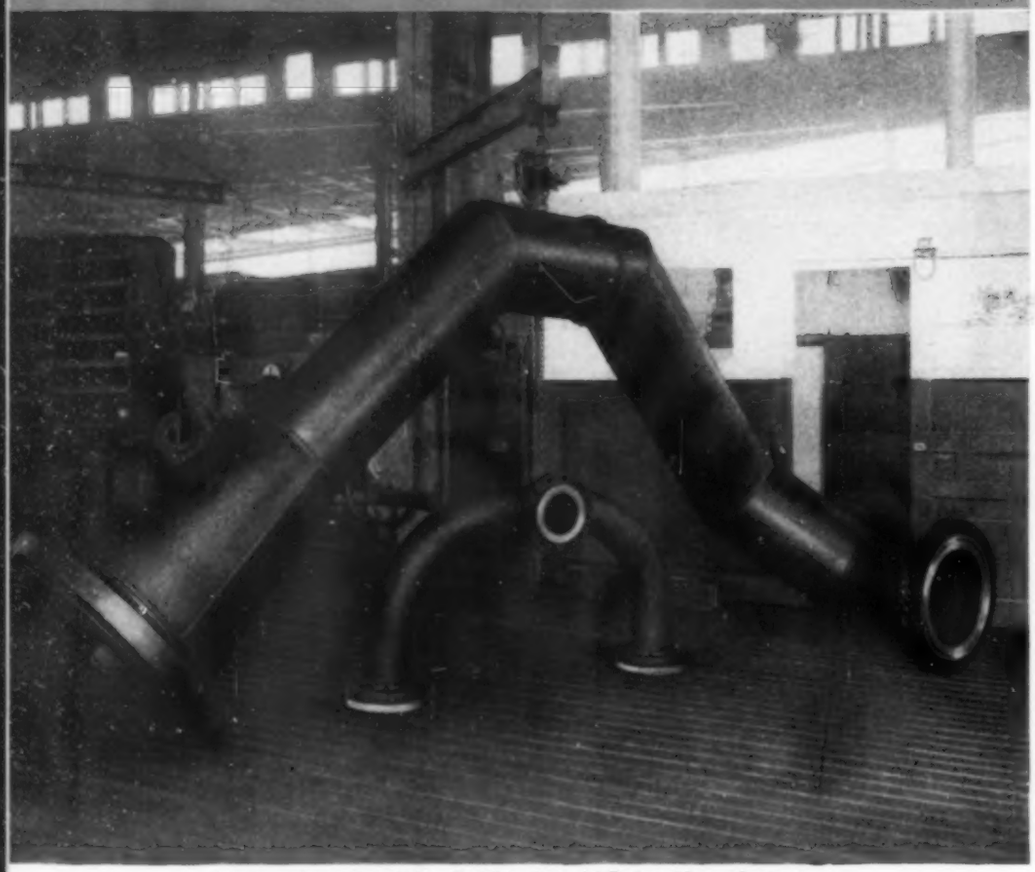

Two examples of Grinnell Pipe Prefabrication: A 20" pipe with complex turns and 20" x 32" increaser for handling hot oil in one of the new Houdry Process oil refineries . . . and an engine header involving 24"-radius U-bend.

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Learn how such sub-contracting can ease your job of providing facilities to produce "enough . . . in time"! Write for booklet "Grinnell Piping Prefabrication". Grinnell Company, Inc., Executive Offices, Providence, R. I. Branch offices in principal cities of U. S. and Canada.

PREFABRICATED PIPING BY GRINNELL

WHENEVER PIPING IS INVOLVED

trically in the U.S.S.R., electrically conductive metal nets are inserted between layers of lumber as it is piled for storage. It is claimed that the resulting artificial drying surpassed natural drying time by 63 percent for birch, by 81 percent for pine, and by 92 percent for oak, with no harmful effects noted in the lumber. In Germany a similar Siemens-Schuckert patent (D.R.P. 698,868) calls for recovery of byproducts too. Green lumber is artificially seasoned in a high frequency field with a wave length of 5-50 m. The drying is claimed to be rapid and thorough, and the special feature is that resins and oils vaporizing along with the moisture are collected and recovered.

Wood represented 30 percent of the total value of Slovakia's exports in 1939. An attempt to industrialize Slovakia's forest areas is being made with the aid of German engineers, and a wood research institute was recently founded in Slovakia to coordinate efforts there. Slovakia cuts 5 million cubic meters of wood yearly, of which 2 million cubic meters are burned as fuel. German engineers are supervising the operation of three wood charcoal plants, also seven Slovak paper factories which supply southeastern European paper exports. In 1940 Slovakia produced 100,000 tons of staple fiber. Although 54 percent of the region's forests are deciduous, only evergreen wood has been processed so far. From sulphite liquor resulting from cellulose production, it is planned to produce wood alcohol in a new plant with 67,000 hectoliters annual capacity. The program in this satellite state, as reported in "Chemische Industrie," calls for manufacturing wood generator gas for motor fuel, briquetting wood charcoal, and producing cattle fodder from wood residues.

Extensive experiments are being carried on in the Reich to utilize more fully the lignin resulting from calcium bisulphite wood treatment processes. About one million tons of lignin are estimated to be available annually in the form of lignin-sulphonic acids. Small amounts of the residue are used as filler for tanning materials, and some is pressed into brickets, but heretofore the remainder has been run into rivers as waste. Lignin has not been useable as an economic fuel, although experiments are being carried out in this direction in the Reich. It is used to a limited extent as a binding substance for wood fiber boards. A more promising process described by Dr. G. Jayme in the "Chemiker Zeitung" calls for hydrating lignin and lignin sulphonic acids by applying pressure in the presence of suitable catalysts to extract valuable solvents and aromatic substances as methyl alcohol, phenol, guayakol, toluol, etc. Wood flour is also mixed with resin as a molding compound filler to give greater strength to plastic compositions. Sisal and other fibers have also been tested for this purpose recently. These experiments could be of little practical im-

portance for the time being, however, because of the lack of availability of sisal on the continent.

Augmenting the Reich's cellulose supplies are imports from Scandinavian countries, especially Sweden. Earlier this year a joint Scandinavian-German committee was set up in Berlin for consultation on economic and scientific problems of the European forest industry. Sweden, which is having a hard time obtaining promised coal from the Reich is reported to be using wood to fire locomotives on secondary railway lines. This has slowed down schedules and reduced train loads.

Used in the manufacture of soft soap, as well as of paints, lubricants and other products, rapeseed oil is being produced on the continent in ever increasing quantities to try to overcome shortages of tropical imported oils. In France, rapeseed cultivation in Burgundy is to be increased considerably. Castor beans are already being raised in large quantities in French Morocco and are now being cultivated increasingly in southern France. In France both rapeseed oil and castor oil are used in the manufacture of soaps and lubricants, the latter especially for airplane engines.

To extract the poison from castor oil residues so that they can be used as a fodder, the Richard Graebner Nahrungsmittelfabriken has developed a new process (D.R.P. 698,200). After the castor oil has been extracted, the plant residue is dried and ground to a fine powder. The powder is boiled repeatedly for short periods in water, which is changed each time. The powder is then filtered, washed with hot water, and dried. This process, which removes the ricin and ricinine, does not affect the albumin, which remains to provide a valuable fodder.

Another process for manufacturing fodder for young cattle was recently patented in the Reich (D.R.P. 698,109) by the Staerkefabrik Kyritz G.m.b.H. It provides for treatment of starchy substances such as potato peelings with hydrochloric acid under high pressure until the dextrose is about 20 percent on a dry basis. The mixture, which is then neutralized and dried, is claimed to keep well and to make an excellent fodder for young cattle.

Iron ore is being used like wood flour and macerated cloth and fiber as a filler to give strength to plastic bearings. Under a process patented by Hans Vogt (D.R.P. 698,105) iron ore is made into sponge iron which is saturated with the plastic. The material is molded into bearings which are claimed to have the advantage that the skeleton of iron strengthens the bearing and dissipates the heat rapidly. Aluminum is also being used by the Vereinigte Aluminum Werke A.G., leading aluminum manufacturer, to make light metal bearings. For this purpose an aluminum alloy whose silicon and iron content is less than .01 percent each, and which contains from .6 to 1 percent copper, and from .5 to 15 percent zinc, is being used.

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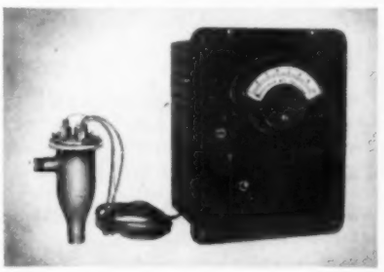

Illustrated at left is the Beckman Automatic pH Indicator—the ideal instrument for modern industrial process operations. Operates continuously from 115 V A.C. mains (no batteries!) and can be installed to give not only continuous *indication* of pH but also a written Record and completely automatic Control over the pH in your plant operations. Ask for Bulletin 16 for complete details on this outstanding instrument.

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PERSONALITIES

G. Lee Camp

Lawrence W. Bass

✦ G. LEE CAMP on June 30 retires as vice president, director and one of the general managers of the Organic Chemicals Division of Monsanto Chemical Co. Born in Midland, Mich., June 11, 1882, he went to work for the Dow Chemical Co. in 1901 as a laborer, rising steadily to attain the position of general sales manager in 1929. When he resigned to join Monsanto it was with the understanding that he was to retire at the age of 60 to engage in personal pursuits. He now plans to grow and market citrus fruits in Florida and follow more aggressively his hunting, fishing and golfing hobbies.

✦ PAUL MARTENS retired as manager of the Metal & Thermit Corp. plant at Carteret, N. J. on April 1 after having completed 33 years of active service. During that time he supervised the development of many new processes and improvements in the detinning operations of his company.

✦ CHARLES M. CRAIGHEAD has been named research metallurgist on the staff of Battelle Memorial Institute in Columbus. He was formerly associated with the Aluminum Co. of America, the Reynolds Metals Co. and the Braeburn Alloy Steel Corp.

✦ GORDON W. MCBRIDE who in recent years has been associated with his father R. S. McBride, as a consulting engineer in Washington, is now a full-time consultant in the Chemical Division of the Office of Agricultural Defense Relations where he is associated with P. H. Groggins.

✦ DR. LEWIS B. MILLER has joined the consulting staff of W. H. and L. D. Betz, of Philadelphia. He will be concerned with problems relating to industrial water purification and sewage and trade waste disposal.

✦ LAWRENCE W. BASS, assistant director of the Mellon Institute since 1937, began his new duties on May 1 as director of the New England Industrial Research Foundation, Inc. In his new post he will engage in a systematic study of the industrial problems of the New England States with special emphasis on wartime requirements and a spread of technical information to small and medium-sized companies. From this basic program will eventually come the planning and placement of research projects for the betterment of the region. Most recent of many activities on behalf of the chemical and chemical engineering profession has been Dr. Bass' work as chairman of the committee on economic status of the American Chemical Society which made its preliminary report earlier this month at Memphis.

✦ LAWRENCE H. FLETT of the National Aniline & Chemical Co., Buffalo, N. Y., will receive the Jacob F. Schoellkopf Medal on May 19. This medal is awarded by the Western New York Section of the American Chemical Society. Mr. Flett graduated from Mass. Insti. of Tech. in 1918.

✦ CLARENCE W. CROWELL, formerly chemical engineer with the Rochester Germicide Co. at Rochester, N. Y., is now located in the Procurement Division of the Chemical Warfare Service at Washington, D. C., as buyer. His official title is lieutenant colonel.

✦ CHARLES H. CURRIER becomes the new president of the Tubular Exchanger Manufacturers' Association. He is vice president and general manager of the Ross Heater and Manufacturing Co., a division of American Radiator and Standard Sanitary Corp. with general offices and plant in Buffalo, N. Y. Headquarters of the association is in New York City.

✦ ROBERT H. RIDGWAY has been named chief of the Coal Economics Division of the U. S. Bureau of Mines. In this capacity he has charge of statistical reviews of all fuel industries, including coke and by-products. He succeeds F. M. Shore, who has been promoted to be assistant chief of the Economics and Statistics Branch.

✦ TOWNES R. LEIGH of the University of Florida received on May 2 the tenth Charles H. Herty award. He was cited not only as an "inspirational teacher of chemistry for almost 40 years" but also as a "forceful factor in the development of the natural resources of Florida." Dr. Leigh is a lieutenant colonel in the Reserve Corps of the Chemical Warfare Reserve.

✦ WALTER M. FENTON, formerly with the Baker & Adamson division of General Chemical Co. has resigned his position to become a member of the executive staff of S. B. Penick & Co. where his new connection will be in the chemical specialties field.

✦ H. W. DODGE, formerly general sales manager of the Texas Company and connected with that organization since 1904, has been appointed assistant deputy director of the Materials Division of the War Production Board. With his new appointment Mr. Dodge becomes third in command of the Materials Division and will take over part of the duties of A. I. Henderson, deputy director of the division that includes the Chemicals Branch.

✦ MICHAEL H. BAKER, formerly chemical engineer with the Calvert Distilling Co. at Relay, Md. is now connected with the Davison Chemical Corp. in Baltimore.

✦ WILLIAM LLOYD EVANS, chairman of the Department of Chemistry and professor emeritus of Ohio State University received the medal of the American Institute of Chemists at the annual meeting in Atlantic City May 16, 1942 for "outstanding service in the science of chemistry and the profession of chemist in America."

✦ ROBYN M. JAMES, post-graduate in bacteriology and food technology from the University of Illinois joined the bacteriological staff of Commercial Solvents and is now working in their new research laboratories in Terre Haute, Ind.

✦ MARSTON TAYLOR BOGERT has been elected honorary member of the council of the Society of Chemical Industry of Great Britain, a life-time post in

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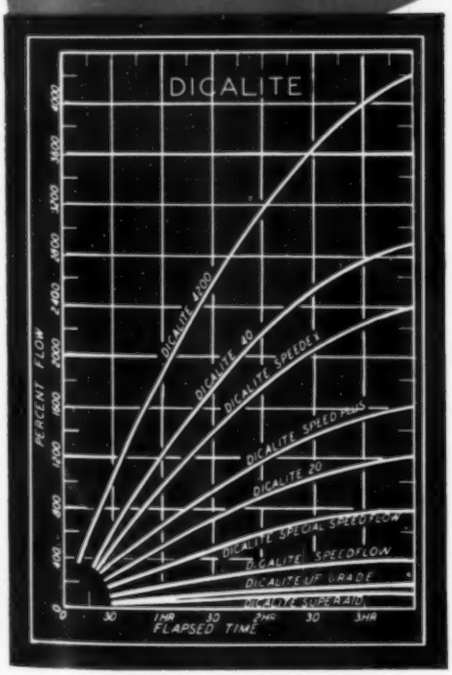
*by conservation of filter cloth...



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. . . contribute to National Defense, make your supply last longer and reduce operating costs.

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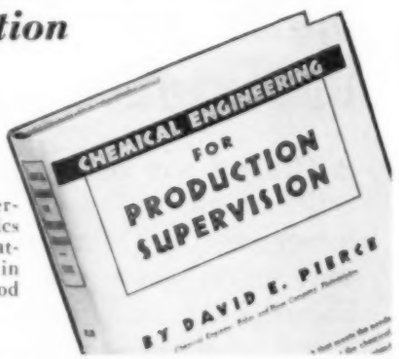

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Raymond I. Bashford

✦ RAYMOND I. BASHFORD, until recently the manager of the Industrial Chemical Department of the Atlas Powder Co. in Wilmington, Del. has been transferred to important defense work in Paducah, Ky.

✦ JULIAN F. SMITH, until recently associate director of the Hooker Scientific Library, is now technical librarian and editor of publications for the Institute of Gas Technology, which is affiliated with the Illinois Institute of Technology in Chicago. Dr. Smith is a leading linguist and technical bibliographer having spent more than 25 years in this work with the Du Pont Company, the B. F. Goodrich Co., Commercial Solvents Corp. and the National Aniline & Chemical Co.

✦ L. S. MCCOLLUM has recently become chief chemist for the Pomona Tile Manufacturing Company and its subsidiaries, the U. S. Diatom Co., Desert Tale & Clay Co. and Western Silicair Corp. He was formerly chemist and research engineer for the Dicalite Co.

✦ R. G. PHELPS, a professional chemical engineer who built explosive plants in the first world war, has been appointed price executive of the Chemical Section of the Office of Price Administration, succeeding Clarence W. Farrier. Previously Mr. Phelps was associate price executive of the Chemical Section. Following graduation from the University of Maryland in 1911 Mr. Phelps was associated with the Du Pont Co. supervising the construction and operation of acid plants, later with Curtiss & Harvey of Canada and when the United States entered the war in 1917, he superintended

construction and operation of a synthetic phenol plant for Aetna Chemical Company of New York and Carnegie, Pa.

✦ EDGAR TURNBULL, formerly of the Wardlow Thomas Paper Co., is now technical superintendent of the Champion Paper and Fibre Co. mill at Hamilton, Ohio.

✦ EDWARD M. MCGOVERN, who received his master's degree in chemical engineering from Lehigh University in 1929, has been named manager of the Solvents Division of the R. & H. Chemicals Department of E. I. du Pont de Nemours & Co. Associated continuously with this organization since 1929, Mr. McGovern served in research, development and production before he was made technical representative for refrigerants, chlorine and chlorinated hydrocarbons in 1934. He succeeds M. Marean who becomes assistant to the Director of Sales for the R. & H. Chemicals Department in Wilmington.

✦ NELSON B. COOPER, who was with the Niagara Alkali Co. until he joined DuPont in 1930, has been transferred from the Solvents Division to the Chlorine Products Division of the R. & H. Chemicals Department. A native of Ontario, Canada, he was graduated from Queen's University.

Louis E. Wise

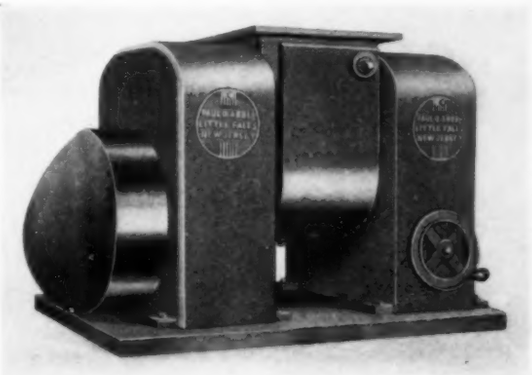
✦ DR. LOUIS E. WISE has been appointed research associate and instructor in wood chemistry in the Institute of Paper Chemistry, Appleton, Wis. Dr. Wise is well known in wood chemistry, cellulose, pulp and paper for his research and review publications in these fields and particularly as co-author, with L. F. Hawley of the Forest Products Laboratory of "The Chemistry of Wood," published in 1926.

✦ DR. FRANK J. TONE, retired April 2 from the presidency of the Carborundum Co. with which he had been associated since 1895. He was succeeded by Arthur A. Batts, formerly secretary of the company. Henry P. Kirch-

IMPROVED MIXER ANNOUNCED BY PAUL O. ABBE

Equipped with Streamlined Supports, completely enclosing gears and stuffing box.

Following the trend of modern laboratory and production equipment toward greater compactness and easier cleaning.



Both Cincinnatus and Mastodon types are included, with capacities from 2 gallons to 300 gallons.

Retaining the popular overlapping principle of mixing blades for fast, efficient mixing.

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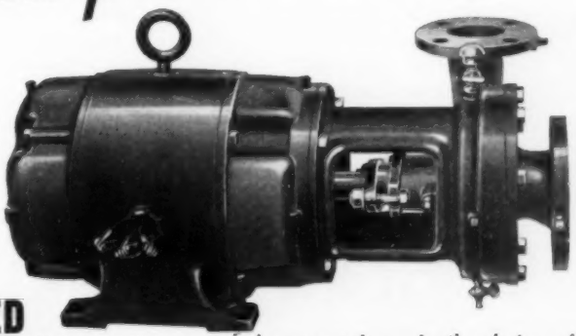
BALL & PEBBLE MILLS • CUTTERS • GRANULATORS • PULVERIZERS • MIXERS

SIMPLICITY — DURABILITY — RELIABILITY

Speed process work!



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And, there is a Frederick Centrifugal Pump for every process job.

★ Long experience in the design of pumps for process work . . . meticulous care in the selection of the right material for the job . . . high standards for heavy, rugged construction . . . qualify FREDERICK to build the pumps you urgently need to expand your capacity. Ask for details! *No obligation!*

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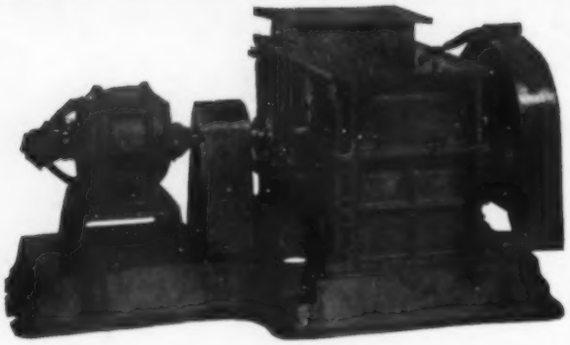

Hammer Mill and Hog

● for grinding and shredding all kinds of fibrous materials such as pulp, wood refuse, roots, asbestos, bark, garbage, tankage, sewage, and chemicals. Note rigid and compact construction—SKF bearings — metal trap — alloy steel shaft — liners — and sectional construction

AMERICAN RING CRUSHERS

Users like the dependable... operation... the simplicity the wide operating range...

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. . . FOR REDUCTION OF CHEMICAL RAW MATERIALS

● More tonnage per hour—more uniform product—minimum fines—no slivers or chips . . . add to this, low power consumption, low installation and maintenance requirements and you have the reason for the ready acceptance of American Ring Crushers by many well known process industry plants. They are realizing substantial economies in grinding all kinds of chemical raw materials. The Rolling Ring Crusher principle—exclusive with us, gives low-cost-per-ton of finished product. All parts are accessible —all parts are tested for quality, wear, and endurance. We guarantee dependable day-after-day service with negligible replacement and maintenance expense. We know and can supply the kind of equipment you need.

AMERICAN PULVERIZER CO.

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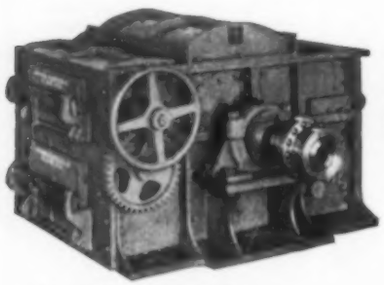

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for grinding glass and tank cullet, salt briquettes, sinter, skimmings, limestone, gypsum, oyster shells, phosphate rocks, etc.

ASK FOR "AMERICAN" ASSISTANCE

Avail yourself of "AMERICAN" engineering service and recommendations for improving your crushing, grinding, pulverizing, and shredding methods. We maintain a testing plant for prospective users of our equipment. Make use of it.

ner was named executive vice president and member of the board of directors. Dr. Tone will continue his general direction as chairman of the board of directors, a new position, in the Carborundum Co. His son, Frank J. Tone, Jr., former sales executive, was elected vice president and board member.

✦ HILLARY ROBINETTE of Commercial Solvents Research Department at Terre Haute, Ind. has reported for active duty with the Chemical Warfare Service of the United States Army.

✦ CARL A. OSTLING resigned as production vice president of the Carrier Corp. on May 1 to assume the post of director of industrial engineering for the United States Rubber Co. with which he was formerly associated. John H. Holton who has been general manufacturing manager of Carrier Corp. now assumes the responsibility of works manager with the title of vice president.

✦ CAPTAIN ADOLPH G. ROSENGARTEN, JR. of Philadelphia has resigned as director of Merck & Co., Inc. because of his duties with the Army and is succeeded by his uncle J. G. Rosengarten, Jr. Captain Rosengarten is on active duty with the 111th Infantry of the 28th Division, United States Army.

✦ JAMES WELLFORD MARTIN, consulting engineer in New York, has given up his consulting practice for the duration of the war in order to accept a position with Sanderson and Porter as chief engineer on the construction of one of the large government arsenals in the Southwest.

Harvey M. Harker

✦ HARVEY M. HARKER of the Organic Chemicals Division of Monsanto Chemical Co. returned, with Mrs. Harker, to St. Louis April 14 from Melbourne, Australia where he had been since November, 1940, as technical adviser in the establishment of manufacturing operations by Monsanto (Australia) Proprietary, Ltd., his company's new Australian affiliate.

✦ DAVID DONOVAN has left the Inter-

chemical Corporation to receive a commission as Ensign in the United States Navy. He is now on active duty at the Naval Air Station in Jacksonville, Fla.

✦ DR. JOHN M. SCHMOELE of Los Angeles is now in active service in the United States Navy and has reported for foreign duty.

Charles W. Dermitt

✦ CHARLES WESLEY DERMITT has joined the heavy chemical sales division of the Pennsylvania Salt Manufacturing Co. in the Pittsburgh office. He had previously been connected with the Pennzoil Co. He succeeds Dean E. McCrory recently transferred to the company's executive offices in Philadelphia.

✦ Two members of the Chemical Engineering Faculty of the University of Michigan are now serving with the nation's armed forces. They are LIEUTENANT COMMANDER ELMORE PETTYJOHN, of U. S. Navy, and CAPTAIN ALLAN FAUST of the Chemical Warfare Service at Edgewood Arsenal. Three members of the Chemistry Department's junior staff, formerly reserve officers, are now in active service as follows: Lieutenant John Covert, Coast Artillery, Lieutenant Louis Gordon, Chemical Warfare and Lieutenant Lowell Perkins, Chemical Warfare.

✦ JAMES C. STARRING, formerly with the Food and Drug Administration in New Orleans is on artive duty as a lieutenant in the U. S. Army stationed at Tampa, Fla.

✦ WALTER S. RAINVILLE, JR., director of the research department of the New Orleans Public Service, Inc. has assumed his new duties as assistant national director of the Local Transport Division of the Office of Defense Transportation in Washington.

✦ JOHN M. SANFORD, for more than 20 years consulting chemist in Terre Haute, Ind. has been called to active duty in the Reserve Officers Pool, Chemical Warfare Service, Edgewood Arsenal.

Homestead Lever-Seald Valves *always* work! Conditions that cause ordinary valves to "stick" . . . viscous fluids, temperature and pressure extremes, infrequent operation, etc. . . . *cannot* make *Homesteads* inoperative. The most stubborn "seizure" yields instantly to hand-applied movement of the lower lever, followed by full opening or closing of the valve with an easy, quarter-turn of the upper handle. This never-failing operation is only one of numerous advantages which include a positive, leakless seal without lubrication; seating surfaces protected in all positions; streamline flow that minimizes pressure drop; and longer, lowest-cost-per-year service. Sizes, styles, metals and alloys to suit most every Process-Industry requirement are available. Put your service problems up to Homestead engineers for sure solution.

For engineering facts about these and other Homestead Valves, write for your copy of Valve Reference Book No. 38.

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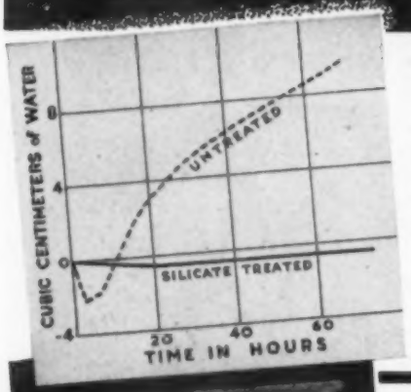
MAKERS OF "PEAK PERFORMANCE" VALVES FOR 50 Years 1892 1942

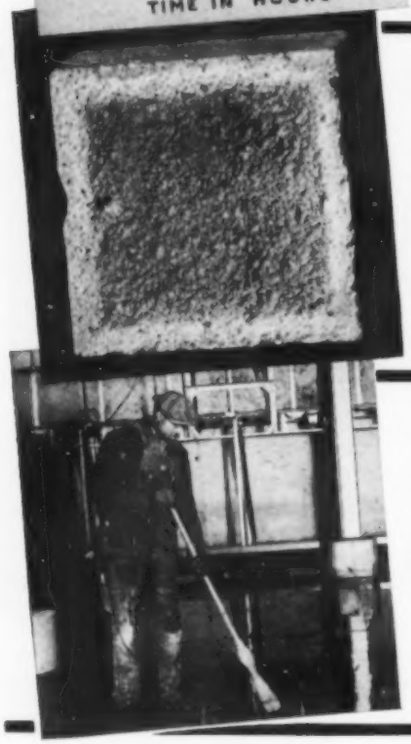
P. O. BOX 13 • • • CORAOPOLIS • • • PENNSYLVANIA

LONGER LIFE *for Concrete*
Treat with Silmac Silicate



WATERPROOFS

Concrete tanks, walls, building blocks, etc., allow water to penetrate to some extent, resulting in dampness and often actual seepage. The efficiency of the Silmac treatment is indicated in the accompanying graph.



DUSTPROOFS

By chemical reaction of the Silmac and the concrete a hard insoluble substance is formed at the surface. Hard, wear-resisting, dustless concrete outlasts untreated concrete. At left, degree of Silmac penetration shown by white outer edges.

ACIDPROOFS

Silmac-treated concrete admirably resists acid attack. Successful applications have been made against hydrochloric, sulphuric, as well as organic acids. Silmac also protects concrete against the attack of brackish water.

Silicates PQ *of Soda*

3 REASONS!

— you should investigate Silmac Silicate for concrete treatment— It's economical—It's easy to apply —It's effective. We'll gladly help you estimate quantity needed for your concrete area. Free bulletin #341 gives complete information.

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Established 1831 General Offices and Laboratory: 125 S. Third Street, Philadelphia, Pa.
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✦ LIEUTENANT EMORY H. KIMBALL, formerly with Monsanto Chemical Co., St. Louis is now on active duty with the Infantry at Fort Sill, Okla.

✦ WILLIS F. HUTCHINSON, formerly of the Mallinckrodt Chemical Works in St. Louis, is in the office of the Chief of Chemical Warfare Service in Washington, D. C.

OBITUARIES

✦ KARL POMEROY MCELROY, chemical engineer and patent attorney, died April 18 at his home in Washington, D. C. Once associated with the late Dr. Harvey W. Wiley, Mr. McElroy became a chemical consultant and patent attorney after leaving federal services in 1905.

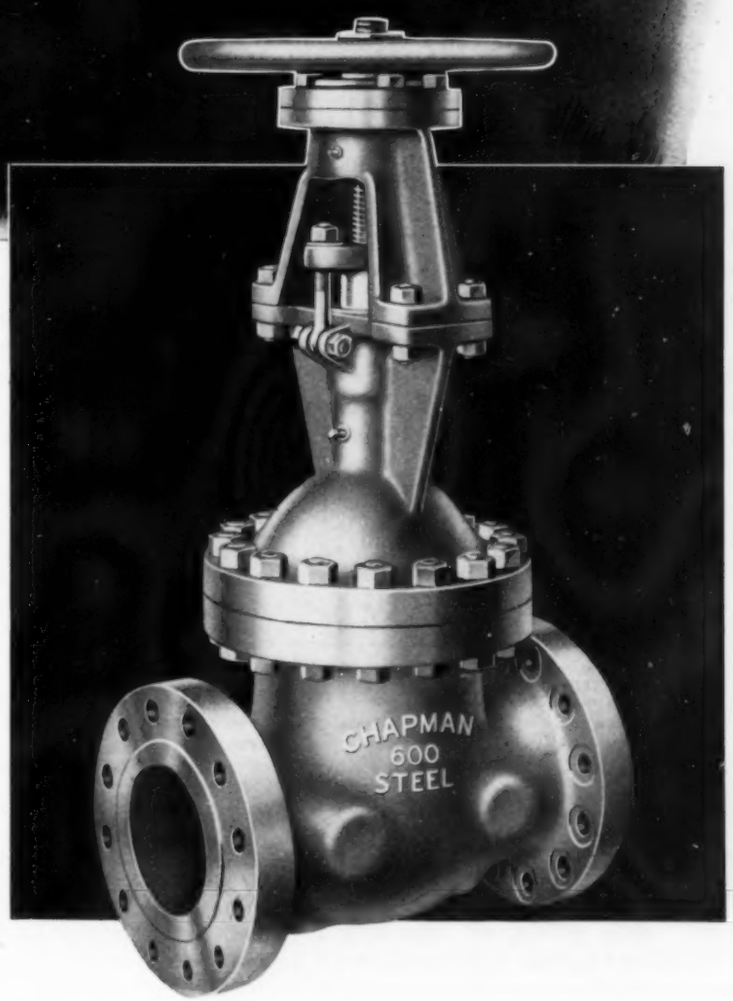
✦ HARRY B. DAVIS, general superintendent of the Permanente Magnesium and Cement operations near San Jose, Calif. was instantly killed in an automobile accident March 24 while returning from an employees' party with other staff members. For over 15 years Mr. Davis had been a key man in the Kaiser organization.

✦ GUSTAVE WHYTE THOMPSON for many years chief chemist of the National Lead Co. and director and officer of several of its subsidiary organizations died April 22 in Brooklyn Hospital after a short illness. He was 76 years old. Dr. Thompson was one of the founders of the American Institute of Chemical Engineers and was its president in 1917-18. He had also served as secretary of the committee of the American Society for Testing Materials which dealt with protective coatings for structural materials. He was vice president of that Society from 1926 to 1927 and its president in 1928.

✦ PHILO B. YANTZY, general manager of the Explosives and Ammunitions group of Canadian Industries, Ltd. died April 22 at his home in Montreal. He was 55 years old. Following his graduation in chemical engineering from the University of Virginia he started his career with E. I. du Pont de Nemours & Co. in 1906 and came to Canada in 1912 as manager of the Explosives plant at Nanaimo. In the first world war he was manager of the British Cordite Company and Canadian Explosives, Ltd.

✦ DR. CARL O. JOHNS, director of research laboratories of the Standard Oil Development Co. from 1920 to 1927, died in Stamford, Conn., April 17 at the age of 71. A native of Sweden, Dr. Johns had lived in the United States since 1879. He completed his education at Yale, where he received his PhD in 1902 and later served there as an instructor. From 1914 to 1920, he was with the U. S. Dept. of Agriculture. Mr. Thompson retired from active duties four years ago.

Owl Eyes...OR ENEMY SPIES?



Imagination, or lack of certain knowledge, can play dirty tricks on you in the dark. But "in the dark" is no place to stay, with an unfamiliar valve-problem staring you in the face. Drag it out into broad daylight immediately . . . with the help of Chapman engineers. See exactly what you are up against . . . whether it's really a special-order job, or one that can be met by Chapman's Standard Line, which includes a wide range of types and sizes originally developed for jobs that seemed just as special as yours. So on all your requirements for bronze, iron, and molybdenum alloy valves and fittings, make it your first move to check with Chapman. For that may well save you a *false move* that would cost you excessive time and trouble.

The
CHAPMAN
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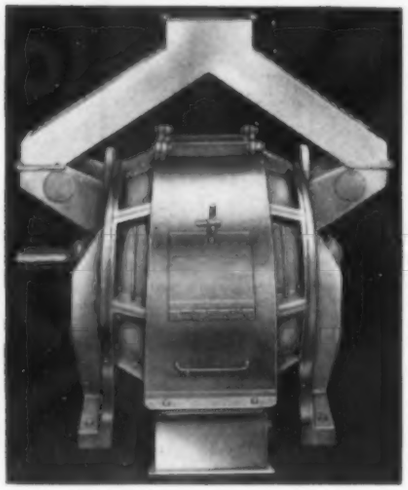
GREATER PRODUCTION *DEMANDS* GREATER CONTROL



Control in processing is going to become more difficult—as it becomes more necessary. Organizations are being disrupted at a time when greater demand for war material and substitutes for metal are adding an increased load to the process industries.

Investigate Prater equipment—for many phases of grinding and mixing it offers complete uniformity of results unfailingly delivered.

Every Prater Mill is sold on a basis of guaranteed output per horsepower hour and control of quality of grind and grain size.

May we analyze your problem?

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PRATER
PROCESSING EQUIPMENT

NEWS OF PRODUCTS AND MATERIALS

AID IN METAL CLEANING

An improved wetting and emulsifying agent for use in connection with all types of alkaline metal cleaners has been developed by the Research Department of the Hercules Powder Co. This new material, known as Dresinate, assists aqueous alkaline solutions in certain applications to replace some of the chlorinated solvents now so scarce because of the shortage of chlorine. The penetrant is a finely divided uniform powder and is available in practically unlimited quantities at a lower cost than the common emulsifying agents used by the metal industry according to the company's announcement.

Addition of 3 to 15 percent of Dresinate to an alkaline cleaning solution, while it slightly reduces the alkalinity, nevertheless increases the detergency of the solution. Its wetting action puts a thin film of alkaline liquid uniformly over the metal surface, wetting out oily areas equally as well as areas free from oil.

The material can be mixed with alkaline cleaners without special equipment since it is a dry powder, readily soluble in water. Its use is indicated for cleaning metal prior to rustproofing, lacquering, painting and cleaning.

GLUE EXTENDER

Animal glue, the critically scarce adhesive which is used in the making of tubular shell containers, ammunition boxes and similar products, can be made to go twice as far by the use of commercial sorbitol solution, according to an announcement by the Industrial Chemicals Department of the Atlas Powder Co., Wilmington, Del. The addition of a small amount of this solution known as "Arlex" has been found to give glues nearly twice the coverage and at the same time, makes possible the use of grades and types of glues that are comparatively plentiful but which must be modified to maintain usual production schedules.

OIL-PROOF RUBBER INSULATION

Recent laboratory tests show that hard sponge rubber made from the Goodrich synthetic Ameripol possesses characteristic resistance to the action of oils, greases and other solvents that are the enemies of natural rubber. The new product is light in weight, thus giving a high degree of buoyancy; can be sawed and drilled; has good acoustic properties; does not show any degree of injury after prolonged subjection to heat of 158 deg. F. Low water and oil absorption make it particularly adaptable as a float material. High resistance to acids and oils broadens its use in chemical engineering applications. Compression tests prove that a mechanical pressure of 225 lb. per sq. in. will not break down or harm its cellular make-up.

AIR-RAID PROTECTION

As protection against the hazard of flying glass during air raids, several companies have recently developed new coatings for windows which are said to be unusually effective.

Window glass or plate glass treated with a new transparent coating developed by Maas & Waldstein Co. of Newark, N. J. and known as Glasshield may break as a result of vibration but it does not shatter, according to the manufacturer. It is also stated that the coating does not interfere with vision or light transmission through the glass. It may be applied on the inner surface of a windowpane with a brush, allowing an hour for the first coat to dry before the second and final coat is added. When no longer wanted, the coating can be removed with a razor blade.

Another coating developed by American chemists and known as Protex shatterproof black-out coating has the property of holding the glass splinters together even though the window may be shattered into thousands of pieces and, in addition, serves as an effective black-out coating by making a window opaque for a year or more under normal conditions. According to Douglas Distributors, Inc. of New York, this coating may be applied with a brush inside of windows and washed off easily with water and a cloth. A weather-resistant outside blackout coating that may be sprayed or brushed on the outside of windows has also been developed by the same firm.

METAL LEAD PRIMER

As an alternative to aluminum paint priming, which has been drastically affected by the Government's freezing order prohibiting the further manufacture or distribution of this well-known protective coating, the Midland Paint & Varnish Co. of Cleveland, Ohio has developed a metal lead primer which, because of its metallic non-rusting components, is claimed to be equal in its protective value to that of a good grade of aluminum paint. Hyspar metal lead primer is neutral gray in color and it will not bleed through the finishing coat or require more than the usual finishing coat required when aluminum is used. It may be brushed, sprayed or dipped and dries hard in 4 to 5 hours. Originally developed for use on metal outdoor displays and large neon signs, it has demonstrated ability to stand up under rapidly changing climatic conditions.

NEW INSULATING VARNISH

Especially developed to meet coil insulation requirements of generators, a new insulating varnish capable of withstanding high temperatures is announced by the Westinghouse Electric & Manufacturing Co. Known as Thermoset, this varnish is a synthetic resin

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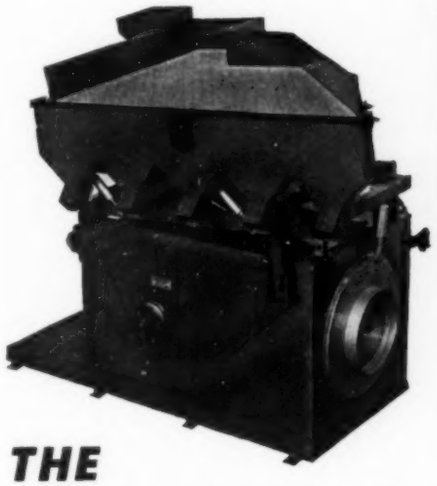
"ALL-OUT"
PRODUCTION

→● A BETTER PRODUCT
→● AND MORE OF IT
→● FOR LESS COST!



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SEPARATOR

Today every hour counts. Separation processing is no exception. The Air-Float Separator speeds processing by (1) handling larger sizes, (2) eliminating fine grinding, (3) reducing slime tonnage. Needs no water supply—locate anywhere (no pipes or pumps to buy or install). Saves space, power costs. Treats materials "wet methods" can't touch, because it's more sensitive to differences in densities. Handles chemicals, ores, *any* dry material or mixtures of different weights.

Laboratory samples tested and recommendations made on request.

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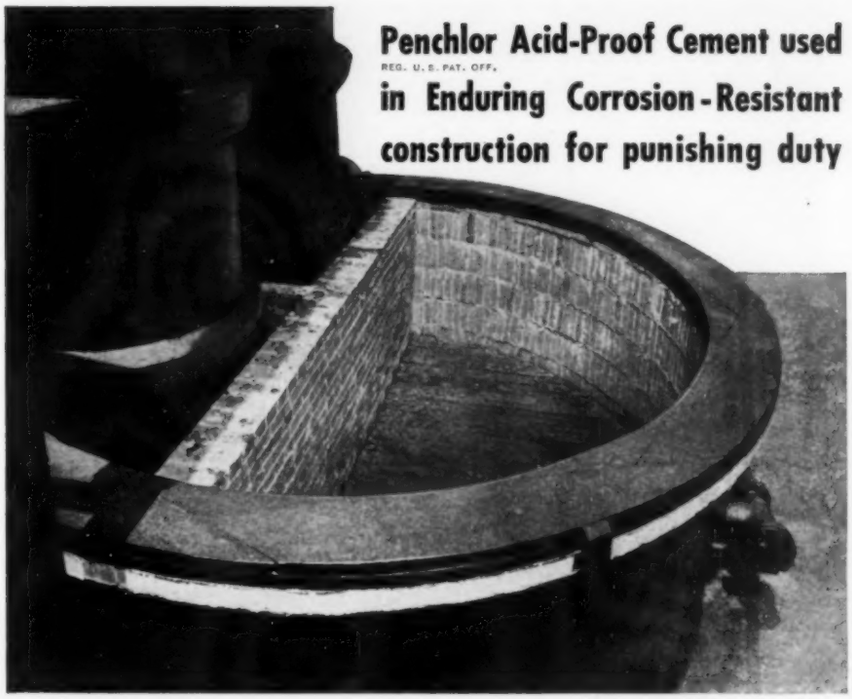

Penchlor Acid-Proof Cement used
REG. U. S. PAT. OFF.
in Enduring Corrosion-Resistant
construction for punishing duty

● This acid-proof, brick-lined tank, in a leading chemical plant, must stand up to the toughest kind of service. Scrap iron, in half ton loads, is dumped into such tanks twice a day, to be treated by hot acid in the manufacture of ferrous and ferric chloride. Some of these tanks have been in service over six years.

For this severe duty, Penchlor Acid-Proof Cement was used in making the mortar for the acid-proof brick lining. This strong, durable sodium silicate cement was chosen because of its proved record of long, unusual service under difficult operating conditions in many important industries throughout the country.

The quick-setting and self-hardening properties of Penchlor Acid-Proof Cement recommend it highly for new construction—particularly now, when time-saving is so important in war efforts. With Penchlor Acid-Proof Cement you can get brick-lined equipment into service without delay.

If you require a cement of exceptional strength and high resistance to abrasion, you will be interested in these Pennsalt *resin* cements: *Asplit*, for conditions always acid . . . *Causplit*, for alternate acid and alkaline conditions. These are easy to handle and will withstand a wide range of corrosive conditions, up to 350 degrees F.

Our engineers have had wide experience handling acids and alkalis in our own plants and are at your service at anytime, without obligation. Write fully. Or, if you prefer, use the coupon.

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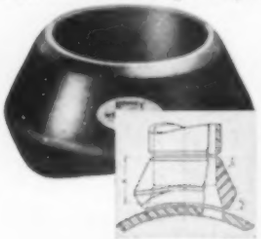
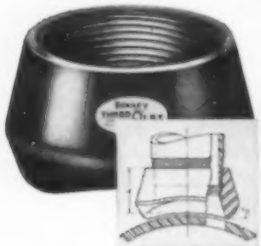
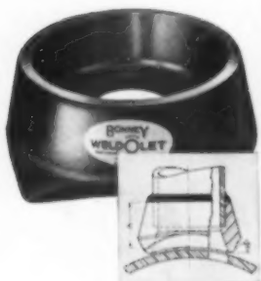
BECAUSE Bonney WeldOlets, ThredOlets and Socket-End WeldOlets eliminate all cutting and threading of the main pipe, they will save time, material and labor in making right-angle branch pipe outlets. Their installation is extremely simple and easy as shown in the illustrations.



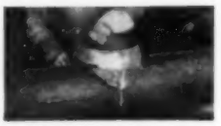
WELDOLET



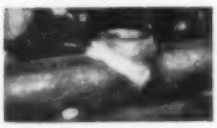
THREDOLET



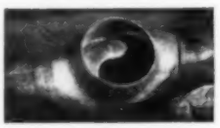
Socket-End WELDOLET



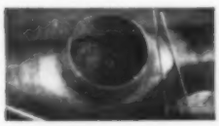
1—Select the position of the outlet. Rub the fitting over the pipe several times to remove scale, dirt—mark center lines—tack into position.



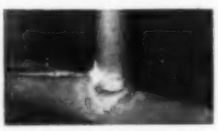
2—Tacking is done in enough places to insure its desired position. No clamps are necessary. Then weld, following and filling the bevel along the base of the fitting. A junction of full pipe strength is assured.



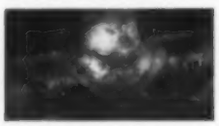
3—When the outlet of the fitting exceeds 2", weld the fitting to the main pipe and then remove the button—in two sections. Where the outlet is smaller than 2" or under unusual conditions on larger sizes, the fitting should be used as a templet and the hole cut in the main pipe first.



4—After the fitting is installed on the main pipe and the button removed, the inside of the joint is in full view for inspection. Interior inspection is impossible with welded pipe-to-pipe intersections, welding tees, saddles, etc. Icicles, scale and excess welding metal are eliminated when WeldOlets, ThredOlets or Socket-End WeldOlets are used. They are removed with the button.



5—The end of the branch pipe is then beveled at 45° and welded to the outlet of the WeldOlet. If ThredOlets are used, the threaded branch pipe is screwed into the outlet of the fitting—or, if Socket-End WeldOlets are used, the branch pipe is slipped into the fitting and an ordinary weld made around the top of it.



6—The job is then complete. Note the trim, mechanical appearance. External as well as interior obstructions are eliminated, saving materials and reducing the weight of the entire system.

WeldOlets, ThredOlets and Socket-End WeldOlets form clean, unobstructed branch connections. Their funnel-shaped intake aperture reduces turbulence and friction. No templets are required, nor is it necessary to do complicated cutting and fitting.

Standard stock fittings are of drop forged steel (outlets from ¼" to 12") in size-to-size and reducing sizes. For special applications, or where unusual conditions exist, they can be supplied in Toncan Iron, wrought iron, brass, Monel, Everdur, etc. and in sizes up to 24" x 24".

They are suitable for every type of piping installation and for all commonly used pressures and temperatures.

Your local distributor will be glad to tell you the complete story about savings which can be effected, or write for Bulletin WT29—TODAY.

Bulletin WT29 —Get your copy of this 20 page book NOW. It gives complete information about WeldOlets, ThredOlets and Socket-End WeldOlets.

BONNEY FORGE & TOOL WORKS

FORGED FITTINGS DIVISION

ALLENTOWN, PA.

type cured by heat-induced chemical polymerization. It sets to an infusible flexible inert film of clear amber color and is high in dielectric and bonding strengths. Waterproof and oil-proof, it is not affected by acids or alkalis in ordinary concentrations.

BUILDERS' PLASTIC

To protect steel and other building materials from atmospheric corrosion an oil-base portland cement product known as Wet-X-Hale is being used as a plastic to produce a firm but tough and flexible finish, particularly on the exterior surfaces of buildings and exposed equipment. Unlike many paint products it is applicable directly to new un-neutralized galvanized steel, to mill-oil black and pickled steel surfaces and even to badly rusted steel structures. The Rogear Company of New York City has applied this material to a number of New York's harbor front properties exposed to severe weather and air conditions. The first of these buildings so coated is now in its third year without showing any blemishes.

POUR-POINT DEPRESSANT

A synthetic material closely resembling a petroleum lubricant in physical properties has been developed by the Monsanto Chemical Co. to enable the refiners of wax-bearing crudes to produce low pour-test oils more economically by avoiding the expense of dewaxing at extremely low temperatures. Good economy and satisfactory results have been achieved by dewaxing to a pour point of 15 to 25 deg. F. and then using Santopour further to reduce the pour point to the required degree. Santopour is said to be effective in a number of different types of oils.

AMERIPOL THREAD

Synthetic rubber thread has been produced from Ameripol for use as a potential war material. It can be used as a substitute for natural rubber in harness for parachutes, in gas masks and respirators as well as in other equipment. No synthetic rubber thread is yet available for civilian use, but preliminary studies show many interesting applications.

PROTECTIVE COATINGS

Tests made in the laboratories of Protective Coatings, Inc., Detroit, Mich. show that it is possible to protect plating and acid tanks, fume ducts, storage and processing tanks, whether made of metal or ceramics, from the corrosive action of concentrated solutions of the principal mineral acids and of the saturated solutions of caustic soda. No effects were shown after 72 hours exposure at 160 deg. F. These Chempruf coatings are applied either as brush-on heavy liquids or as a plastic which hardens to withstand heavy-duty service. The softening point is 300 deg. F. and the melting point is over 500 deg. F. These coatings will not resist mineral solvents, in which respect they are no better than natural rubber, but their resistance to acids and alkalies far surpasses that of either

natural or synthetic rubber according to the announcement of the manufacturer.

SKIN PROTECTIVE

As a guard against skin irritants and products likely to cause industrial dermatitis, a bland skin-protective cream has been developed by Sabern Products Co. of Cleveland, Ohio. It is rubbed into the hands, the portion of the arm exposed, around the finger joints and under the nails before the worker starts his shift. Man-O forms a film-like invisible and flexible glove, protecting the skin from absorbing grease, cutting oils, paints, and other matters difficult to remove.

GLASS-METAL SEAL

Tight seals between iron and glass, eliminating the need for nickel and cobalt for wires leading into certain types of vacuum tubes are now being made in accordance with a new process developed by Dr. Albert W. Hull and Dr. Louis Navias of the General Electric Research Laboratory.

Since nickel and cobalt are used in many ways for war equipment, and their supply is extremely limited, the new invention is an important one for certain applications. It permits tight seals because the glass compositions are developed to expand with heat at the same rate as that of the metal. The series of different glass compositions can be used with iron and certain iron alloys. One consists of 45 percent of silicon, 14 percent of potassium oxide, 6 percent of sodium oxide, 30 percent of lead oxide and 5 percent of calcium fluoride. The rate of expansion of this glass is very close to that of iron.

A related and separately patented invention of Dr. Navias is useful when a glass containing lead is sealed in contact with iron. Ordinarily in such instances the lead atom migrates from the glass into the metal, thus weakening the joint. Dr. Navias proposed placing a thin layer of lead-free glass directly over the metal, then sealing the lead-containing glass to that. The thin glass layer prevents the lead from reaching the iron, yet is not thick enough to crack and let the air in.

NON-FOGGING SHEET MATERIAL

Four patents recently issued to the Celanese Corp.. of America relate to non-fogging sheet material made of cellulose acetate or similar material for use in such military items as gas masks, respirator eye and face pieces and observation panels of aircraft. According to the claims of these patents the material may be made by superficially saponifying one side only of cellulose acetate sheet material so that the other side of the sheet is more capable of absorbing moisture. The non-fogging material can also be made by laminating a sheet of cellulose acetate which is resistant to moisture with another sheet of cellulose acetate material which is capable of absorbing moisture readily.

★ In one of their recent bulletins on hoists, the National Safety Council says:

"Hooks which have become bent on account of overloading should not be straightened and put back in service, but a new hook should be provided. When a hook is once bent the stress in the metal tends to weaken it so that afterward its strength is a matter of doubt and cannot be depended upon."

That's good advice. With the lives of American boys utterly dependent upon our industrial production, this is no time to take chances which may cause lost time accidents to men or machines, or both.

Watch the Hooks. Wright load hooks are drop-forged from special steel which, when subjected to excessive overloading, give visible warning by opening slowly. When the bottom hook has started to open, look to the top hook, too, for while it is stronger than the bottom hook, it also may be reaching a danger point.

Don't Abuse Your Hoist. Now that we are all faced with restrictions and shortages proper maintenance is of paramount importance. While every **WRIGHT HOIST** is built with load-carrying factors considerably in excess of their rated capacities, like many other well-made pieces of mechanical equipment built for specific duty, they should not be overloaded. Overloading is dangerous—to men, materials, machinery and steady production. Remember—abuse to machinery today is akin to sabotage. Conserve steel and maintain production schedules by careful use, regular inspection and proper lubrication.

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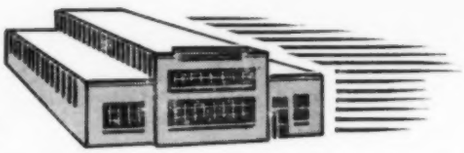
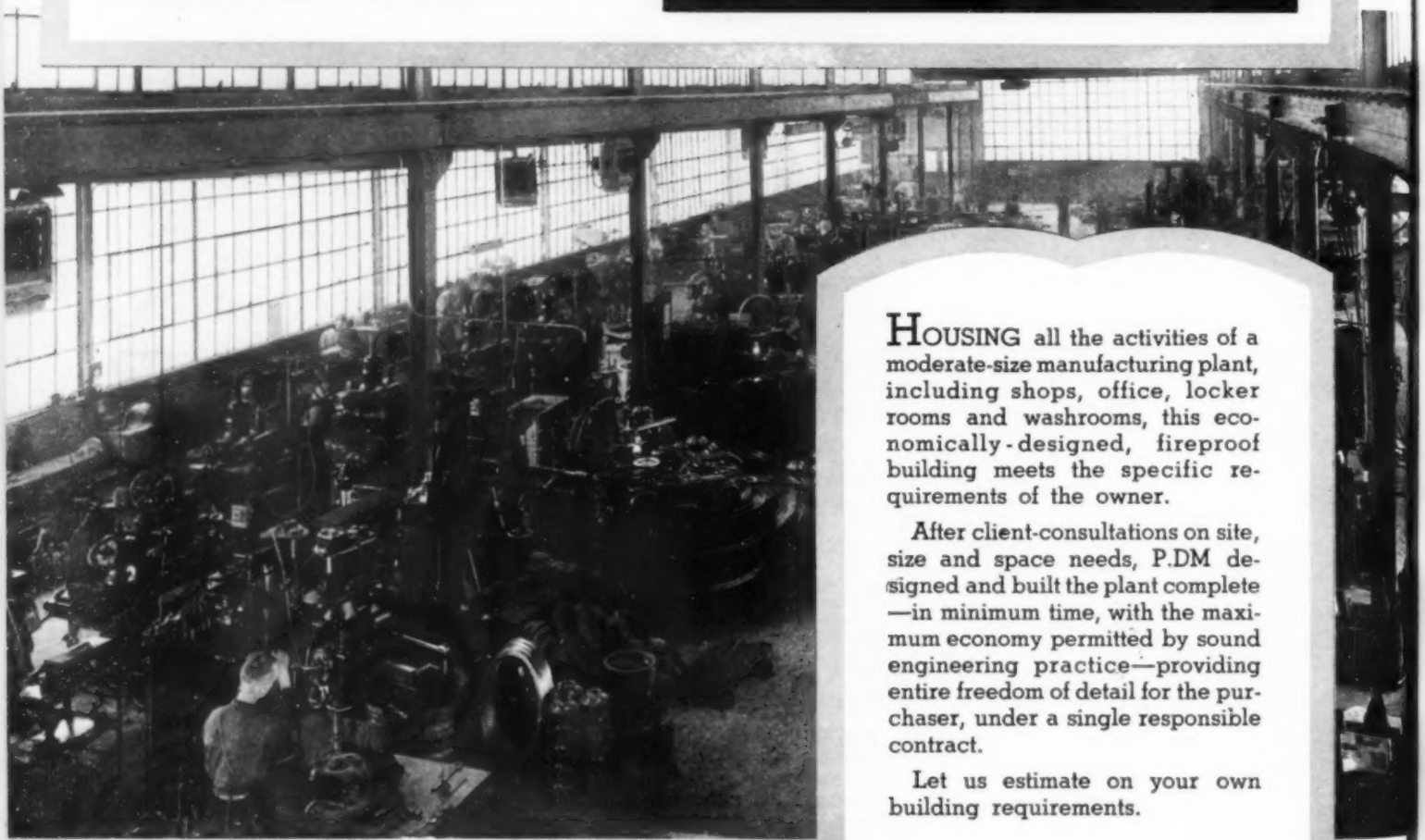


A TYPICAL, RAPID, DEPENDABLE AND SATISFACTORY INDUSTRIAL BUILDING JOB *by*

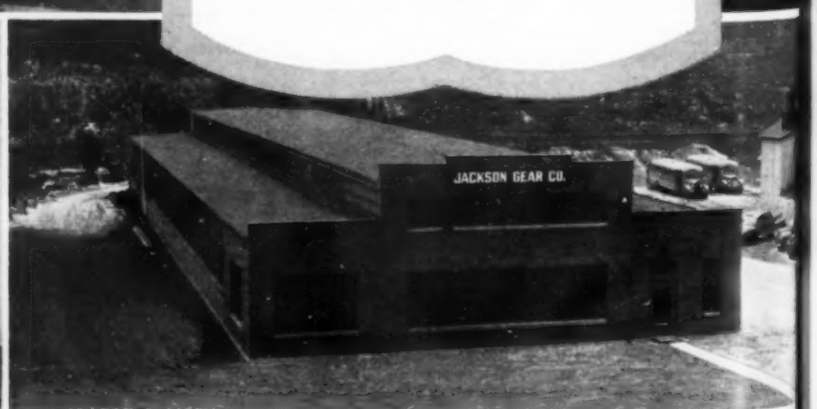
PITTSBURGH •DES MOINES



HOUSING all the activities of a moderate-size manufacturing plant, including shops, office, locker rooms and washrooms, this economically-designed, fireproof building meets the specific requirements of the owner.

After client-consultations on site, size and space needs, P.DM designed and built the plant complete—in minimum time, with the maximum economy permitted by sound engineering practice—providing entire freedom of detail for the purchaser, under a single responsible contract.

Let us estimate on your own building requirements.



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National Fertilizer Association Meets in White Sulphur Springs

CHEM & MET

NEWS OF MEETINGS & CONVENTIONS

ORGANIC CHEMICAL MANUFACTURERS TO MEET IN JUNE

THE SYNTHETIC ORGANIC Chemical Manufacturers Association will hold its annual meeting and outing at the Seaview Country Club, Absecon, N. J., June 5-6. There will be a short business meeting on Friday and the annual golf tournament is scheduled for Saturday. Charles Mace, secretary of the association, is in charge of all arrangements. The Manufacturing Chemists' Association will hold its annual meeting in New York on June 4 at the Waldorf-Astoria.

PAINT CONVENTION IN ATLANTIC CITY DURING OCTOBER

ANNUAL CONVENTION of the National Paint, Varnish and Lacquer Association and of the Federation of Paint and Varnish Production Clubs will be held in Atlantic City, October 25-31. Headquarters for the convention will be in the Traymore and the Claridge hotels. Due to uncertainties as to transportation and other unforeseen circumstances which may exist in October, arrangements with the hotels have been made subject to cancellation should this become necessary or advisable.

COLLOID SYMPOSIUM TO BE HELD DURING JUNE

THE 19TH COLLOID Symposium, held under the auspices of the Committee of Colloid Science of the National Research Council and the Colloid Symposium Committee of the Division of Colloid Chemistry, American Chemical Society, will be held in Boulder, Colorado, June 18-20.

Inquiries regarding facilities and other information should be addressed to Frank E. E. Germann, University of Colorado, Boulder, Colo.

SOCIETY FOR PROMOTION OF ENGINEERING EDUCATION MEETS

IT WAS RECENTLY announced that the fiftieth annual meeting of the Society for the Promotion of Engineering Education would be held in New York City at Columbia University on Saturday and Sunday, May 27 and 28. The meeting will be devoted to a consideration of "The Engineering College at War." Inquiries should be directed to Prof. H. E. Walter, Newark College of Engineering, Newark, N. J., chairman of the Publicity Committee for the annual meeting.

JUNIOR CHEMICAL ENGINEERS DISCUSS PROFESSIONAL DEVELOPMENT

MEETING MAY 25 at Childs Restaurant, 109 West 42nd St., New York City, the Junior Chemical Engineers of New York will hear Dr. W. E. Nichols, executive head of the research department of the South Charleston Division of Westvaco Chlorine Products Co., and chairman, Professional Guidance Committee, American Institute of Chemical Engineers, speak on the general subject of professional development and recognition for the young chemical engineer. The topic of Dr. Nichols' talk will be "Are You a Chemical (?) Engineer?"

CEREAL CHEMISTS MEET IN CHICAGO

THE ANNUAL MEETING of the American Association of Cereal Chemists is to be held at the Edgewater Beach Hotel in Chicago, May 18–21. In all, 64 technical papers and addresses have been listed to cover various phases of the chemistry and technology of the cereal industry.

Because of the importance that nutritional problems have assumed, the symposium on Flour and Bread Nutritional Supplements will be especially promising. Among the speakers on this symposium will be Dr. C. A. Elvehjem, University of Wisconsin, Dr. R. R. Williams, Bell Telephone Laboratories of New York, and Mrs. C. G. Snyder, of the Wheat Flour Institute.

TEXTILE CHEMISTS MAKE PLANS FOR ANNUAL MEETING

THE AMERICAN Association of Textile Chemists and Colorists is now making plans for its annual meeting late this year, according to T. R. Smith, president. However, the date and place have not yet been definitely selected. Kenneth H. Barnard, of the Pacific Mills, has consented to serve again as chairman of the Technical Program Committee for the 1942 annual meeting. This program will be devoted primarily to textile and chemical problems related to the country's war effort and suggestions regarding suitable topics should be referred to Mr. Barnard.

MANY TECHNICAL MEETINGS NOW BEING SCHEDULED

AMONG THE TECHNICAL association meetings and conventions of interest to chemical engineers and industrial chemists now being planned for the summer and fall months are the following:

American Society of Brewing Chemists, Hotel Netherland-Plaza, Cincinnati, Ohio, May 25–27.

American Leather Chemists Association, annual meeting, Deshler-Walleck Hotel, Columbus, Ohio, June 1–2.

Scientific Apparatus Makers of America, annual meeting, Hotel Hershey, Hershey, Pa., June 1–3.

Institute of Food Technologists, annual meeting, Hotel Nicollet, Minne-

CALENDAR

JUNE 8-10	**National Fertilizer Association, 18th annual convention, Greenbriar Hotel, White Sulphur Springs, W. Va.**
JUNE 22-26	**American Society for Testing Materials, annual meeting, Chalfonte-Haddon Hall, Atlantic City, N. J.**
SEPT. 7-11	**American Chemical Society, 104th meeting, Buffalo, N. Y.**
SEPT. 29-30	**Technical Association of the Pulp and Paper Industry, Statler Hotel, Boston, Mass.**
NOV. 9-13	**American Petroleum Institute, 23rd annual meeting, Stevens Hotel, Chicago, Ill.**

THE LATEST INFORMATION ON HIGH EFFICIENCY LOW COST DUST CONTROL

HERE are two brand new books on Dust Control that every foundry should have. One contains information on the "Dustube" cloth bag type dust collector (Catalog No. 72); the other describes the "High Efficiency Cyclone" dust collector (Catalog No. 82). Both have sections on engineering data that contain up-to-the-minute facts on modern dust control. Write for one or both of these catalogs today.

AMERICAN FOUNDRY EQUIPMENT COMPANY
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AMERICAN HIGH EFFICIENCY DUST COLLECTORS

apolis, Minnesota, June 15 – 17.

National Fertilizer Association, 18th annual convention, Greenbriar Hotel, White Sulphur Springs, W. Va., June 8–10.

American Institute of Electrical Engineers, Chicago, Ill., June 22–26.

American Society for Testing Materials, 45th annual meeting, Chalfonte-Haddon Hall, Atlantic City, N. J., June 22–26.

American Chemical Society, 104th meeting, Buffalo, N. Y., Sept. 7–11.

Technical Association of the Pulp and Paper Industry, Statler Hotel, Boston, Massachusetts, Sept. 29–30.

American Society of Mechanical Engineers, fall meeting, Rochester, N. Y., Oct. 12–14.

American Petroleum Institute, 23rd annual meeting, Stevens Hotel, Chicago, Ill., Nov. 9–13.

American Institute of Chemical Engineers, 35th annual meeting, Netherland Plaza, Cincinnati, Ohio, Nov. 16–18.

National Chemical Exposition and National Industrial Chemical Conference, Stevens Hotel, Chicago, Ill., Nov. 17–22.

SELECTIONS FROM CONVENTION PAPERS

NICKEL PLATING MAGNESIUM ALLOYS

A METHOD FOR electrodepositing adherent nickel plates on magnesium alloys has been developed. The process consists of a series of steps in which the metal is first etched slightly in a chromic-nitric-sulphuric acid bath, then treated in a hydrofluoric-nitric acid solution to deposit a fluoride film prior to being plated with nickel from a nickel borofluoride bath. Both nickel fluoride and borofluoride plating baths have been studied extensively. The deposits obtained on magnesium alloys are soft, adherent, and easily buffed to a high luster. They withstand indoor and dry atmospheres very well, but are not recommended for moist corrosive conditions due to corrosion of the magnesium produced by the nickel-magnesium couple through porosity in the deposits.

Magnesium alloys may be readily electroplated with adherent nickel deposits. To obtain these deposits, the basis metal is buffed and cleaned in the usual manner. The buffing compound is removed in a solvent such as perchlorethylene and the metal is given a cathodic cleaning in a bath of the following composition:

	Oz. per Gal.
$Na_2CO_3.10\ H_2O$	7.4
$Na_3PO_4.12\ H_2O$	14.5
NaOH	3.7
Na_2SiO_3	7.4
Sodium lauryl sulphate	0.9

Cleaning time is usually about 1 min. at a current density of 50 amp. per sq.ft. and at a temperature of 158-194 deg. F. The piece is then washed with hot and then cold water.

After washing, the piece is then dipped in the chrome-pickle etch bath, which has the following composition:

	Oz. per Gal.
Chromic anhydride	15.8
Nitric acid	10.4
Sulphuric acid	0.007

All chemicals in this bath are of the C.P. grade. The dipping time should be about 2-8 seconds at room temperature. After thorough washing, the piece is dipped in a solution of 10 percent hydrofluoric acid and one percent nitric acid for 1-5 minutes.

After another washing, the magnesium alloy is electroplated with nickel in a nickel borofluoride bath containing a slight excess of boron and 3-7 grams per liter of fluorine over that required to form $Ni(BF_4)_2$. The deposit may be readily buffed to a high finish and chromium plated.

W. F. Loose, metallurgist, Dow Chemical Co., Midland, Mich., before the Electrochemical Society, Nashville, Tenn., April 15–18, 1942.

EFFECTS OF LEWISITE AND MUSTARD WARFARE GASES

PROLONGED EXPOSURE to either mustard or Lewisite in concentrations barely detectable by odor will cause casualties. Mustard gas usually has an odor similar to that of garlic or horse-radish, while Lewisite has a biting odor similar to that of geraniums. Lewisite is more volatile at low temperatures than mustard and is therefore more dangerous in cold weather.

Differences in the physiological action of Lewisite and mustard gas are summarized in the following table:

	Mustard	Lewisite
Immediate Effects;		
Skin	None, even from liquid	Sharp tingling from liquid.
Nose	None	Breathing vapor for few minutes causes sharp burning irritation.
Eyes	None from vapor. Mild irritation from liquid.	Immediate severe pain from liquid.
Skin burns	Much itching; little pain. Blisters filled with clear fluid and surrounded by an area of erythema (redness).	Painful as well as itching; blisters filled with cloudy fluid. No surrounding erythema (redness).
Late Effects;		
Skin	Burns only skin	Burns through skin into muscles.
Eyes	Severe inflammation but rarely scarring with loss of vision.	Inflammation more severe and usually causes some scarring and permanent impairment of vision.
Entire Body	Produces no systemic (internal) poisoning	Produces systemic poisoning with arsenic.

George L. McCoy, chemical engineer, before The Junto, Philadelphia's Adult School, 16 South 10th Street, Philadelphia, Pa., March 13, 1942.

New Problems Require New Solutions

Increased demands placed on the chemical and its allied trades have led to the adoption of various substitutes. These substitutes create new problems and new problems require new solutions.

The solution to many processing problems is available through the use of the SPROUT-WALDRON defiberizing mill illustrated above.

The defiberizing mill is being successfully used in defiberizing rags, alpha pulp, wood chips and many other materials that are being used in the War Production Program.

In addition to the above unit, SPROUT - WALDRON designs and manufactures a complete line of processing equipment for problems involving grinding, sifting, cutting or crushing. Send us details of your requirements in order that we may make a study of them and give you the benefit of our experience. In doing so you will not be placing yourself under any obligation.

Sprout, Waldron & Co.

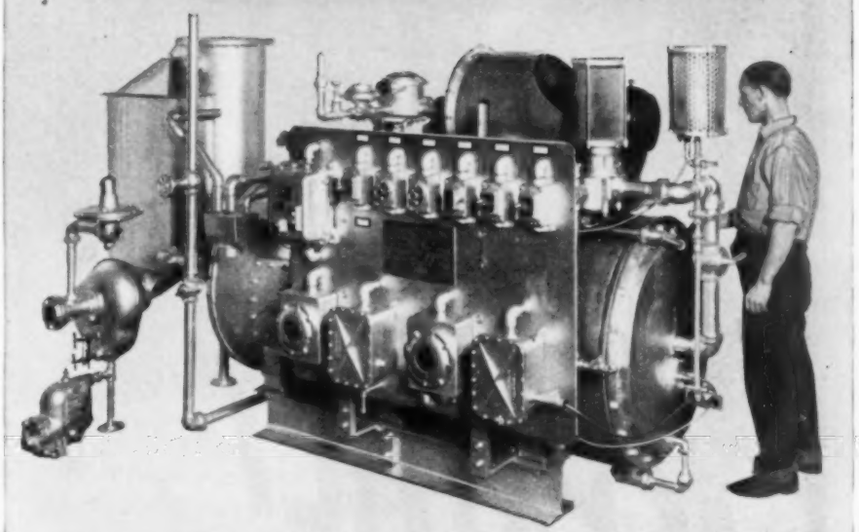
(INCORPORATED IN 1895)

115 Sherman St. Muncy, Pa.

Engineers—Designers—Manufacturers
Since 1866

For INERT GAS

Only Complete Control Can Give *EXACT* RESULTS



INERT GAS of constant, predetermined analysis is assured through exclusive Kemp features that are not to be duplicated in other equipment. Complete premixing of fuel gas and combustion air to *exactly* the proportions desired is one of these. There are others of equal importance. Investigate.

Kemp Inert Gas Producers are available in capacities of 1,000 to 100,000 c.f.m. for operation on artificial, natural or liquefied petroleum gases.

Ask for Bulletin 901.3. Address **The C. M. Kemp Manufacturing Co., 405 East Oliver Street, Baltimore, Maryland.**

KEMP of BALTIMORE

ASPHALT

has to be pumped

DRIVING to the office this morning you probably enjoyed hard asphalt paving without thinking that *it once had to be pumped* before becoming a street. We mention pumping asphalt because it is one of the many less common industrial, chemical and process products that Quimby pumps are handling in routine service.

Because pumps are frequently stuck away in corners or overpowered by other machinery of greater size their importance is sometimes underestimated until trouble occurs. The next time you are looking for a pump that you can count on to stay on the job ask Quimby engineers for their recommendation. They have been at this business for half a century and have plenty of practical experience.

THE BEST PUMP FOR THE JOB
IS THE MOST ECONOMICAL PUMP TO USE

QUIMBY PUMP COMPANY, INC.
351 Thomas St., Newark, N. J.

QUIMBY PUMPS

Better Pumping Practice
SINCE 1894

OXIDATION OF PROSPHORUS IN PRESENCE OF CARBON MONOXIDE

GASES PRODUCED in reducing phosphates in a blast furnace or an electric furnace contain both phosphorus and carbon monoxide. It is advantageous to conserve the CO for use as fuel, particularly for preheating air for the blast furnace. Since the ignition temperature of phosphorus is much lower than that of CO, it appeared that the phosphorus could be oxidized preferentially and the P_2O_5 separated from the CO.

For gases containing one percent phosphorus and 39 percent CO, almost complete oxidation of the phosphorus was accomplished at 500-700 deg. C. with about 160 percent of the theoretical air requirement for oxidation of the phosphorus to P_2O_5. About one percent of the CO was oxidized. At 1100 deg. C. preferential oxidation of the phosphorus in this gas was possible in the presence of phosphate rock, with which the P_2O_5 immediately reacted to form calcium metaphosphate.

For gases containing seven percent phosphorus and 90 percent CO, substantially complete oxidation of the phosphorus occurred at 550-600 deg. C. with 125 percent of the theoretical air requirement, and about two percent of the CO was oxidized. With gases of both compositions, the presence of water vapor increased the oxidation of CO. Control of combustion rates was important.

G. L. Frear, E. F. Ogg, and L. H. Hull, Tennessee Valley Authority, Wilson Dam, Ala., before the American Chemical Society, Memphis, Tenn., April 20–24, 1942.

• • •

The war budget of $56,000,000,000 is estimated to require 154 billion kw.hr. of electric energy annually. This exceeds the total production of energy for all electric utilities in the United States in 1940. Production of aluminum alone for the goal of 60,000 new planes this year will require 8.5 billion kw.hr.

CONTINUOUS PROCESS FOR ALCOHOLIC FERMENTATION OF MOLASSES

STANDARD PRACTICE for the production of ethyl alcohol through the fermentation of various sugar-containing substances (molasses, cereals, etc.), involves a batch procedure of 48-72 hours duration. A process was sought that would be continuous and in which sugar concentrations normally used in the batch method could be fermented to completion in a short time. This continuous system was to involve a minimum number of fermentation vessels.

Such requirements were met in the development of a laboratory system utilizing a single fermenter and in the establishment of experimental conditions whereby approximately 12 percent sugar solutions could be completely fermented in 3-5 hours.

Rates of addition and withdrawal for this system were determined on a 12 percent dextrose-yeast water medium and a 10-25 percent rate was found satisfactory, depending on the initial yeast cell count. Various types of molasses,

Cuban blackstrap, refined, and beet were also continuously fermented in the system at the usual molasses mash concentration. Depending upon the type of molasses fermented and experimental conditions such as initial cell count, supplements, etc., it was found possible to ferment molasses in a 5-10 hour cycle.

H. R. Bilford, R. E. Scalf, W. H. Stark, and P. J. Kolachov, Research and Development Department, Joseph E. Seagram & Sons, Inc., Louisville, Ky., before the American Chemical Society, Memphis, Tenn., April 20–24, 1942.

• • •

A recent survey indicated a possible saving of 35 percent of the aluminum used by the paper and pulp industry through (1) substitution of steel for aluminum angles for doctors and (2) replacement of aluminum white water trays with resin-bonded plywood. A 22 percent possible saving in Monel was indicated through the substitution of wooden white water trays in place of this alloy.

• • •

PROCESSES FOR PRODUCING METALLIC MAGNESIUM

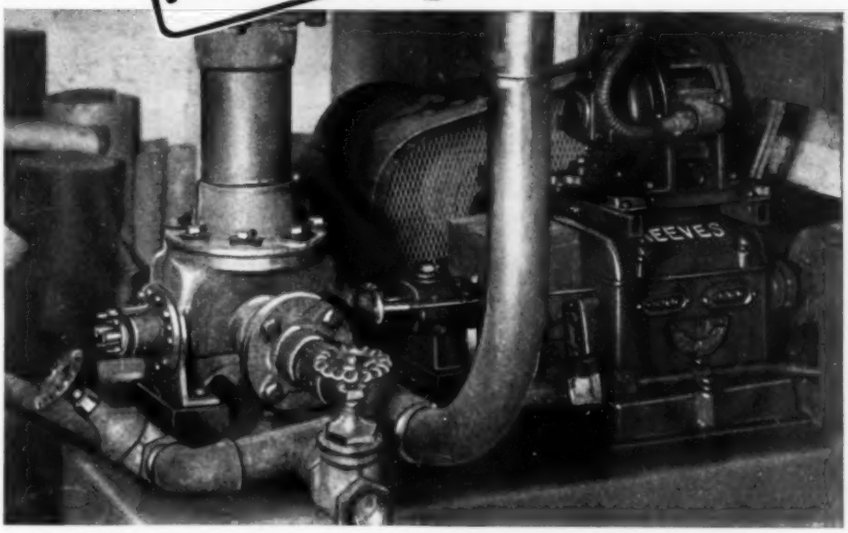
THE MAGNESIUM METAL pioneers in this country were The Dow Chemical Co. and the American Magnesium Corp., but the latter dropped out in 1927. The metal came from the electrolysis of fused 85 percent magnesium chloride, $MgCl_2.H_2O$, which was recovered from brines in the Midland area. These brines contained NaCl, $CaCl_2$, a little Br_2 and about 3 percent $MgCl_2$. The bromine was more important than the magnesium, use of the latter being restricted largely to photographic flash powder and aluminum alloys. Over a period of years, Dow developed a special type of electrolytic cell which produced cathode metal of high purity and byproduct hydrochloric acid.

Another electrolytic process was developed in Germany by the I. G. Farbenindustrie and later used in England by Magnesium Elektron, Ltd. This process depended on the electrolysis of fused $MgCl_2$, but the English electrolyte was made from Grecian magnesite. High-grade magnesite low in lime was calcined and converted into $MgCl_2$ with chlorine obtained partly from gases evolved from the magnesium cells and partly from electrolysis of NaCl.

Recently The Dow Chemical Co. constructed a plant in Texas to use sea water as its raw material, although the magnesium content is only 0.13 percent. Sea water is treated with hydrated lime from calcined oyster shells. Magnesium hydroxide is precipitated and then reacted with hydrochloric acid produced from gases evolved from the electrolytic cells. The solution of $MgCl_2$ is evaporated to 85 percent salt, which is fused and electrolyzed in the molten condition.

Recently it was decided to duplicate the Elektron process and its electrolytic cell in a plant now being built by Basic Magnesium, Inc., in Nevada. Magnesite is concentrated by flotation and then calcined in Herreshoff roast-

Any Required Pressure and Capacity with Reeves Equipped Pumps

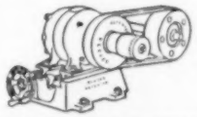


(Courtesy Quimby Pump Company)

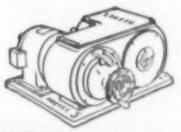
Pumps equipped with REEVES Variable Speed Drives can be depended upon to maintain constant pressure, or to vary the pressure or capacity exactly as needed. Pictured above is a Quimby Screw Pump installed in a coated paper mill. This pump, which has been in continuous operation since 1935, handles heavy starch paste against a pressure of 100 pounds per square inch. It is equipped with a REEVES Variable Speed Transmission, through which the pressure and capacity can be instantly and accurately regulated without stopping the pump. REEVES Speed Control is standard equipment on many types and makes of driven machines used in chemical and processing plants, and can be easily installed on machines in use. Send for Catalog G-419, describing complete REEVES line.

REEVES PULLEY COMPANY, *Dept. CM,* **Columbus, Ind.**

VARIABLE SPEED TRANSMISSION for infinite speed control over wide range—2:1 through 16:1. Fractional to 87 h.p.



VARI-SPEED MOTOR PULLEY for application to shaft extension of any standard constant speed motor; 3:1 range. To 15 h.p.



MOTODRIVE—combines motor, variable speed drive and gear reducer (if needed). To 10 h.p.; speed range 2:1 through 6:1.

Accurate Variable **REEVES SPEED CONTROL**

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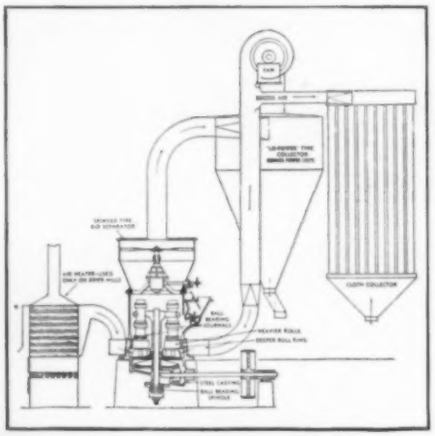
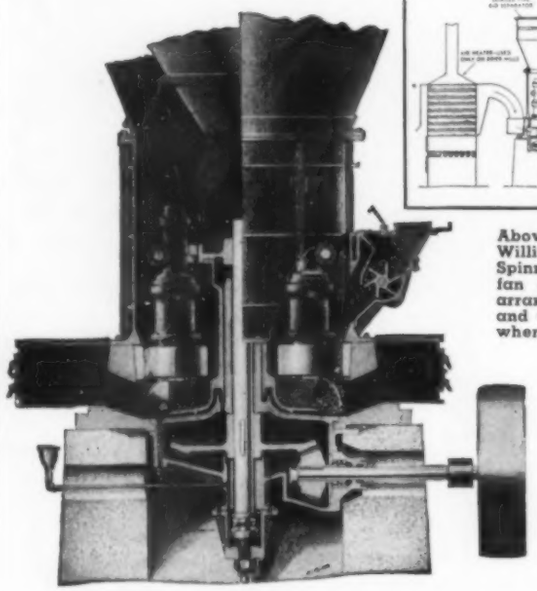


Above shows general layout of Williams Improved Roller Mill with Spinner Air Separator, collector, fan and cloth auxiliary collector arranged for simultaneous drying and grinding. Air heater is omitted when no drying action is involved.



Sectional view showing heavy duty construction of the Williams Roller Mill, conceded to be the most practical for medium and extremely fine grinding. Not only has the mill the ability to grind fine, but due to air separation, provides a positive check on the size of the product.

HIGH OUTPUT ON UNUSUALLY FINE PRODUCTS . . ANY FINENESS FROM 20 MESH TO MICRON SIZES . . . . .

When grinding to extreme finenesses Williams Improved Roller Mills give unusually high output with a minimum of power per ton ground. Any fineness from 20 mesh to micron sizes can be obtained with Williams Air Separators. Instant changeability from 70%–100 mesh to 99.9%–325 mesh.

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ers. The MgO sinter is then converted by Cl_2 to an anhydrous $MgCl_2$ cell feed. The calcined magnesia is ground and briquetted with coke and peat moss from British Columbia. As a possible substitute for magnesite, dolomite is being investigated and pilot plant work is now under way.

Diamond Alkali Co. and Mathieson Alkali Works, Inc., which have been producing waste $CaCl_2$ liquor from their ammonia soda plants, will also produce magnesium. Their process will probably treat calcined dolomite with waste $CaCl_2$ liquor and then carbonate with gases from the calcining kilns. The $CaCO_3$ is filtered off and the $MgCl_2$ solution evaporated to 85 percent.

Diamond will use the Dow type of cell. Some of the feed will be produced with waste liquor, some made by direct treatment of calcined dolomite with hydrochloric acid produced from gases evolved from electrolytic cells. The chlorides will be reacted with hydrated dolomite, yielding $Mg(OH)_2$ and $CaCl_2$, which will be carbonated with the kiln gases. Calcium carbonate is precipitated, and the resultant $MgCl_2$ solution evaporated and dried to 85 percent.

Mathieson plans to use a type of cell developed jointly by its staff and that of Consolidated Mining & Smelting Co. The Mathieson cell has the advantage that concentrated Cl_2 gas is produced as a byproduct instead of dilute hydrochloric acid and Cl_2 as in the Dow cell. It will also probably require less electric current per pound of magnesium.

Union Potash Co., a subsidiary of International Minerals and Chemicals Corp., obtains a waste liquor carrying 16-18 percent $MgCl_2$ from its potash-base-exchange plant in New Mexico. This will be used, after evaporating and drying, as part of the cell feed in a plant now being constructed in Texas. The remaining portion of the feed will come from dolomite and hydrochloric acid produced from gases evolved from the cells, subsequently treated with hydrated dolomite and carbonated with kiln gases, as in the alternative Diamond method.

All the methods described will use 85 percent $MgCl_2$ as feed except the M.E.L. cell to be used by Basic Magnesium, Inc. The latter cell requires an anhydrous feed. For electrolytic magnesium, large quantities of electric power are essential, as each pound of metal recovered requires from 11-16 kw.hr. This means that each ton of annual production requires 2.8-3.2 kw. of firm connected power.

Recently Henry J. Kaiser constructed a plant to use the Hansgirg process for metallic magnesium through the carbothermal reduction of calcined MgO. In this process a mixture of coke and calcined magnesia is heated in an electric arc furnace to a temperature of about 2100 deg. C. The vaporized metal is "shock-cooled" with natural gas, and the finely divided magnesium separated from the gases by Cottrell precipitators. The powder, contaminated with carbon and some MgO, is mixed with oil and redistilled. The magnesium distills

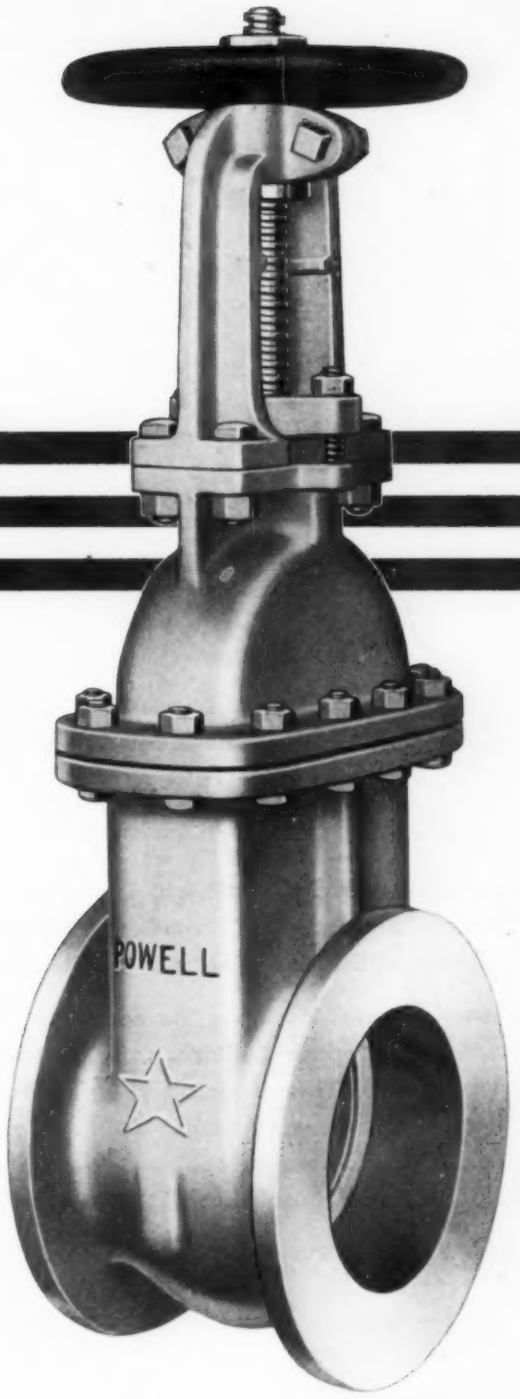

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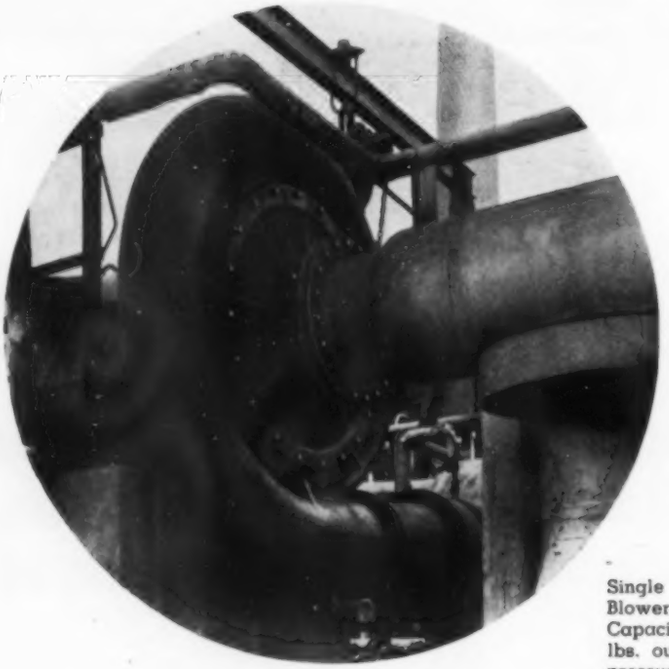
Fig. 2453
This Flanged End O. S. & Y. Gate Valve—available in pure metals and special alloys (Monel, nickel, stainless steel, aluminum, acid bronze, etc.)—is especially adapted for installations requiring large-size, corrosion-resistant valves. Sizes from 2½" to 30". Also made in screwed ends—Fig. 2452—in sizes from 2½" to 6".

VALVES



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about 1,000 lb. of metal per hour, using a carbothermal reduction with molten lead spray as the cooling and collecting medium for the distilled magnesium. Ford has nearly completed a carbothermal plant using oil cooling which is expected soon to be producing a ton of metal per day.

Of all these processes the electrolytic is the surest and safest, but requires much electric power and the plants are slower and more expensive to build. The ferrosilicon process has no such record of commercial application, but it seems to be certain and rapid with a low capital cost per pound of production.

Philip D. Wilson, Chief of Production, Aluminum and Magnesium Branch, War Production Board, before the American Institute of Mining and Metallurgical Engineers, New York, N. Y., Feb. 10, 1942.

NEW PROCESS FOR TREATMENT OF SEWAGE AND INDUSTRIAL WASTES

As a result of experiments over several years, a new process known as the "Alternating Double Filtration" method has been developed for treatment of sewage and certain industrial wastes.

By the usual method of treatment of sewage in percolating filters, the sewage is first passed through screens and tanks to remove solid matter. The settled liquid is then distributed over a percolating filter through suitable stationary jets or by means of moving sprinklers. With average domestic sewage, the rate at which the liquid can be treated is ordinarily about 70 gal. per day per cu.yd. of filtering medium.

In treating waste waters from milk depots and from manufacture of certain milk products it was found that treatment by single filtration gave satisfactory purification for a time, but that the quantity of solid material in the top layers soon clogged the filter. It was then discovered that excessive quantities of solid matter could be removed if the filter was treated for a week or two with purified effluent from another filter.

This observation led to laboratory experiments in which the effluents were first passed through one percolating filter and then through a second similar filter. After the filters had been in operation for about two weeks, the effluents were supplied to the second filter and the treated liquid from this was passed through the first. The order of the two filters in series was changed at intervals. By this process of alternating double filtration, the difficulties of excessive accumulation of solid matter were avoided. One experimental plant was operated under such conditions for a period of three years without serious difficulty.

Two large experimental filters are now employed for the treatment of sewage by alternating double filtration. These are efficiently treating about three times the quantity of sewage per cu.yd. of medium that could be treated by single filtration alone.

Work has shown that the limit has

not been reached at a rate of 420 gal. per day per cu.yd. of medium with the new process, and that in summer months the limiting factor was the time of contact. Cost figures have shown that the process begins to be economical at rates in excess of 50,000 gal. per day and that it would probably be best at a rate of 500,000 gal. per day.

Dr. A. Parker, Acting Director of Water Pollution Research of the Department of Scientific and Industrial Research, before a joint meeting of the Institution of Chemical Engineers and the Chemical Engineering Group of the Society of Chemical Industries, London, England, Dec. 9, 1941.

• • •

Alloy coatings for steel are receiving increasing attention. One new development is the "Corronizing" process. This consists of a coating of a number of very thin layers of metals and alloys having unusual corrosion-resisting properties. Zinc and nickel or tin and nickel are electro-deposited in thin layers, then heat treatment is employed at 500-750 deg. F. to alloy the metals as a uniform coating.

• • •

CHEMICALS FROM THE PETROLEUM REFINING INDUSTRY

ISOPROPYL ALCOHOL made from propylene was the first chemical to be manufactured on a commercial scale from raw materials supplied by the petroleum industry. Today, a number of different reactions are used to change saturated and unsaturated hydrocarbons from refining processes into chemical products. The H_2SO_4 absorption of olefins followed by hydrolysis and other reactions is still the most important means of producing a variety of alcohols, ketones, ethers and other products. Chlorination is used in the preparation of amyl alcohol and its derivatives from pentane. By the chlorohydrination or oxidation of ethylene, followed by other reactions, ethylene glycol and its derivatives are prepared.

In addition, a number of chemicals such as butadiene, toluene and ethyl alcohol are now being furnished by the petroleum industry for war uses. The same war chemicals have great potential peace-time utilization, and the production capacity resulting from the present abnormal demand will be reflected in the chemical industry during peace-time. Whenever there has been available large quantities of an inexpensive chemical, new uses have always followed with surprising rapidity.

Development of a process for preparation of synthetic glycerol from propylene has been characterized as the most significant chemical achievement since the fixation of atmospheric nitrogen. The future of synthetic glycerol lies in its ability to stabilize prices and to guarantee a virtually inexhaustible potential supply of high-grade glycerol at a reasonable price. These factors will stimulate industrial research on new uses and development and expansion of present uses.

Of especial interest to the chemical industry is the number of chemicals now being made available as byproducts

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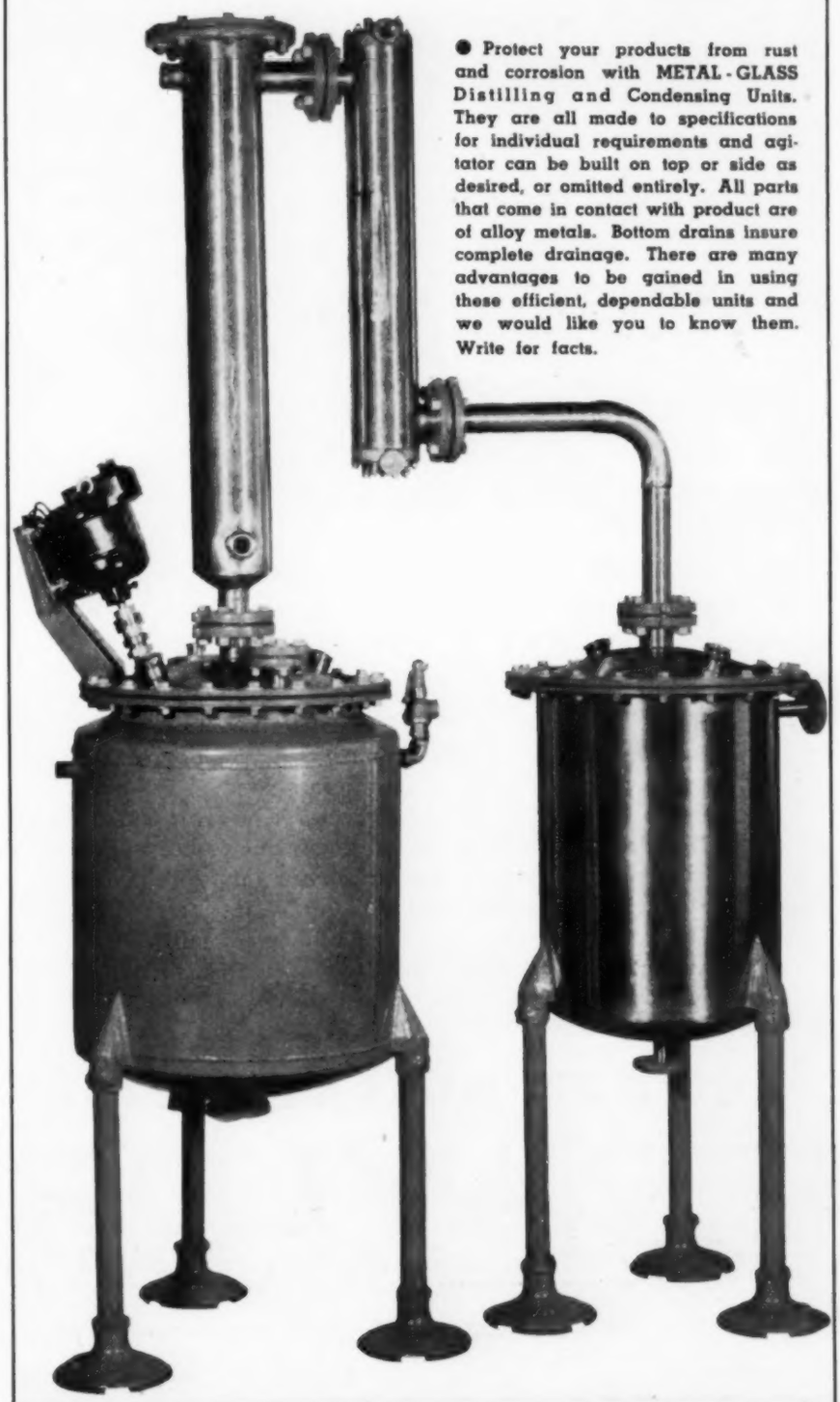

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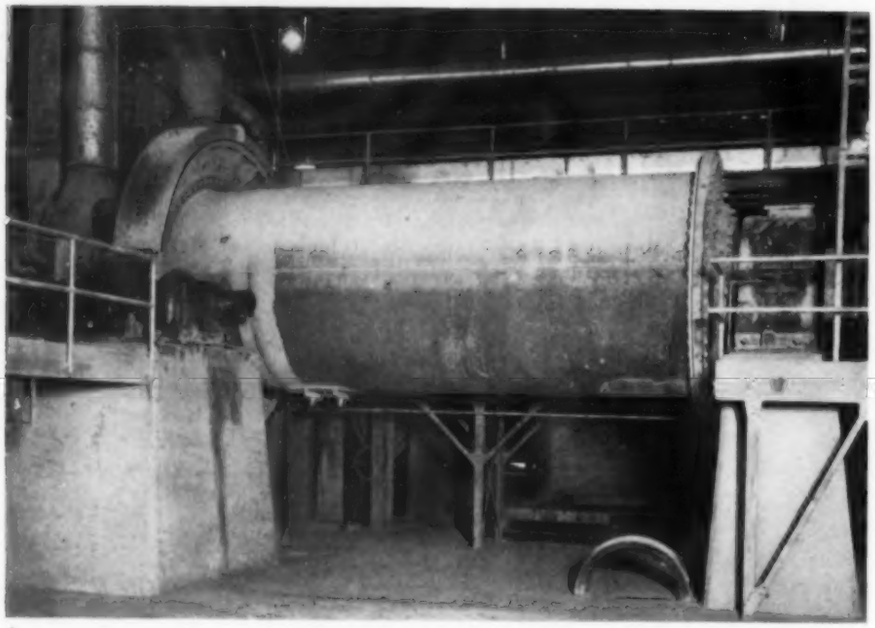

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and intermediates of the glycerol process. Among these is allyl chloride, used to make allyl alcohol, mustard oil and various soporifics and the anaesthetic cyclopropane. Esters of allyl alcohol are used in perfumes and resins and the mono- and dichlorohydrins and epichlorohydrin have potential uses in solvents, plastics and pharmaceuticals.

An entirely new field of organic chemistry has been made possible by the nitroparaffins. The four nitroparaffins already available have a potential range of usefulness unequalled by any other new group of organic chemicals. They offer many new compounds as well as providing better methods of manufacturing such well-known compounds as hydroxylamine and chloropicrin. The hydroxylamine salts result from acid hydrolysis of primary nitroparaffins.

Production of ammonia has also been undertaken by one oil company. This concern found that in the process of preparing refinery gases it became necessary to remove isobutylene by absorption in concentrated H_2SO_4. This acid absorption mixture was subsequently diluted with water and the olefin recovered as tertiary butyl alcohol. The dilute H_2SO_4 could not be reconcentrated economically. However, a plant was constructed for the fixation of atmospheric nitrogen as ammonia utilizing the hydrogen present in the refinery gases and this ammonia was then used to neutralize the dilute H_2SO_4 to form fertilizer grade $(NH_4)_2SO_4$.

Soon the demand for ammonia and $(NH_4)_2SO_4$ became so great that the supply of hydrogen had to be supplemented by cracking natural gas. This cracking to produce more hydrogen introduced the problem of utilizing the carbon formed simultaneously. This soft carbon has found its greatest use in the compounding of rubber for tubing, hose, gaskets and mechanical goods.

Lewis F. Hatch, Department of Chemistry, University of Texas, Austin, Texas, before the American Association for the Advancement of Science, Dallas, Texas, December, 1941.

CONSERVATION OF CRITICAL MATERIALS IN PAPER AND PULP INDUSTRY

A RECENT SURVEY conducted by the American Paper and Pulp Association has indicated a possible 22 percent savings in brass and bronze castings used by the pulp, paper and paperboard industry for repair, replacement and operating supplies.

This savings can be accomplished by (1) extending the life of cast screen plates by rolling and recutting, chrome-plating or wearing slots to wider apertures than present standards (rolling and recutting should approximately double the life of plates); (2) substituting cast iron, malleable iron or steel in all services except those exempted by Copper Order M-9-c because of chemical process service and acid pulping processes. For example, it was suggested that brass and bronze should be eliminated in pipes and fittings by substituting the above ma-

terials or wood, wood-lined, asbestos-cement products, cement-lined steels, ceramics, glass or lead. Pulp runners and parts not essential to the functional performance of the unit can be eliminated. Parts of copper or its alloys not essential for the functional performance of a unit include (1) screen frames on coarse knotter and fine rotary screens; (2) chest agitator castings and shaft sleeves; (3) tank inserts; (4) bearing housings or brackets; (5) doctor and roll supports; (6) all ornamental trim such as handwheels, roll journal caps, etc.; (7) sulphite digestor blow pipes on downstream side of blow valve, for which heavy cast iron pipe with test holes can be substituted; (8) target plates in sulphide blowpits for which cast iron or wood can be substituted.

A possible savings of 17 percent in lead consumption was indicated by substituting ceramic pipe and linings for lead, and by substituting spray towers for defective SO_2 gas coolers where replacement is necessary. Approximately 15 percent of the tin used by the industry could be saved through the increased use of salvaged babbitt and by plastic painting of beater bars in place of tin plating. Possible savings of 24 percent in zinc consumption can be accomplished by substituting asbestos corrugated sheeting or wood in place of galvanized sheets and by substituting plastic paints for galvanizing.

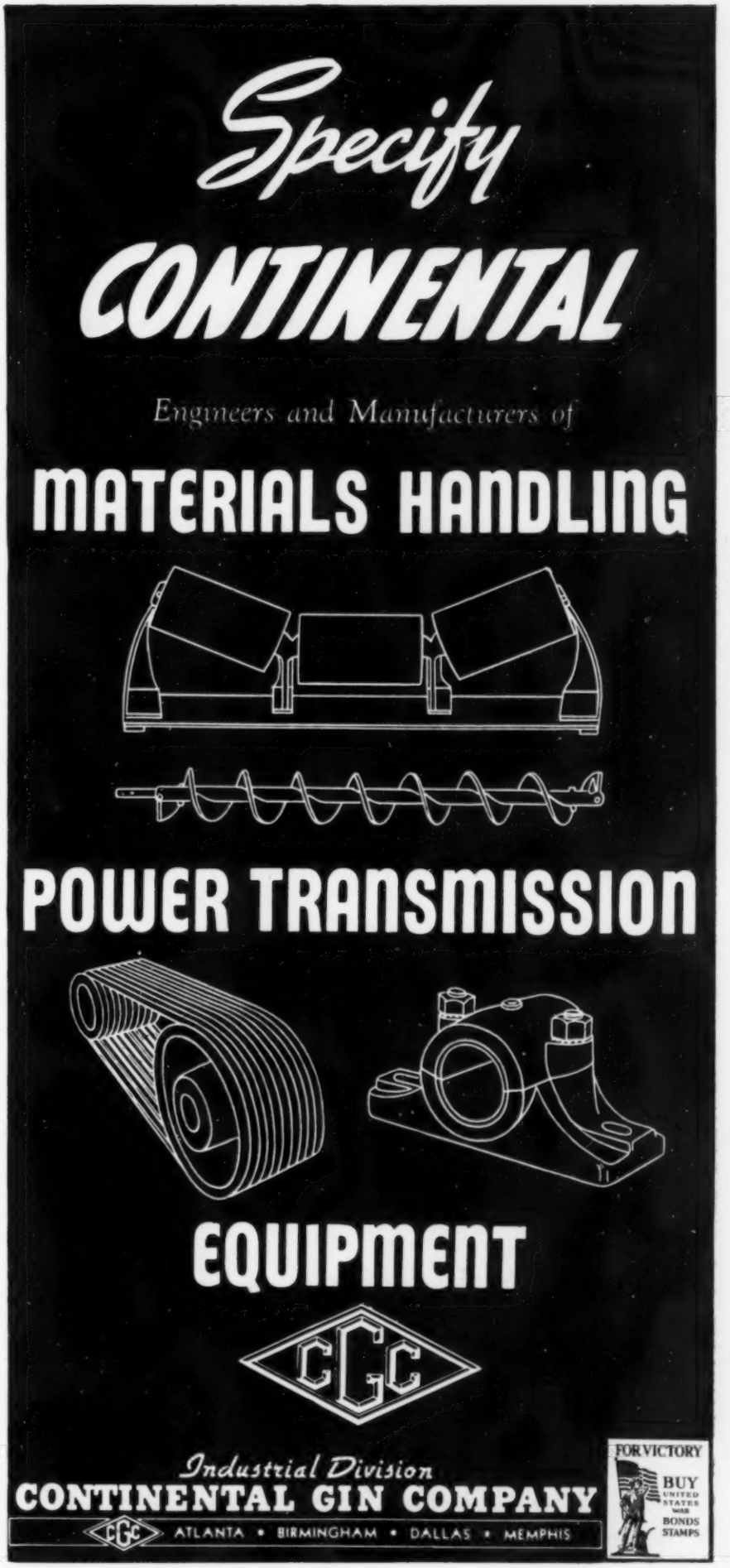
Recommended methods for saving about 23 percent of the formaldehyde consumed by the industry include: (1) conservation by reduction in amount used even though the present paper standards may require slight revisions; (2) substitution of satin white in coating formulas or cutting casein with ammonia to render it non-water soluble; (3) substitution of other organic materials which are less critical to national defense, provided they may be developed for commercial use (for example, tetrahydroxydioxane).

Rubber can be conserved by substituting leather, cotton impregnated with asphalt or phenolic resin compounds for rubber belting, by substituting sulphite pulp sheets, phenolic resin sheets or asbestos for packing and gaskets, by providing improved storage and supervision of rubber boots, and by giving more careful supervision and attention to maintenance of the mechanical condition of rubber rolls.

S. E. Kay, R. W. Hovey, and Hugo Hanson, OPM Committee for the Conservation of Critical Defense Materials, American Paper and Pulp Association, December 31, 1941.

SABOTAGE IN INDUSTRY

From January 1915 until March 1917, approximately 104 incendiary fires, explosions or the discovery of unexploded bombs occurred. The estimated loss from incendiary fires in 1916 was at least 25 million dollars, or 15 million dollars above the normal loss. In plants manufacturing ammunition



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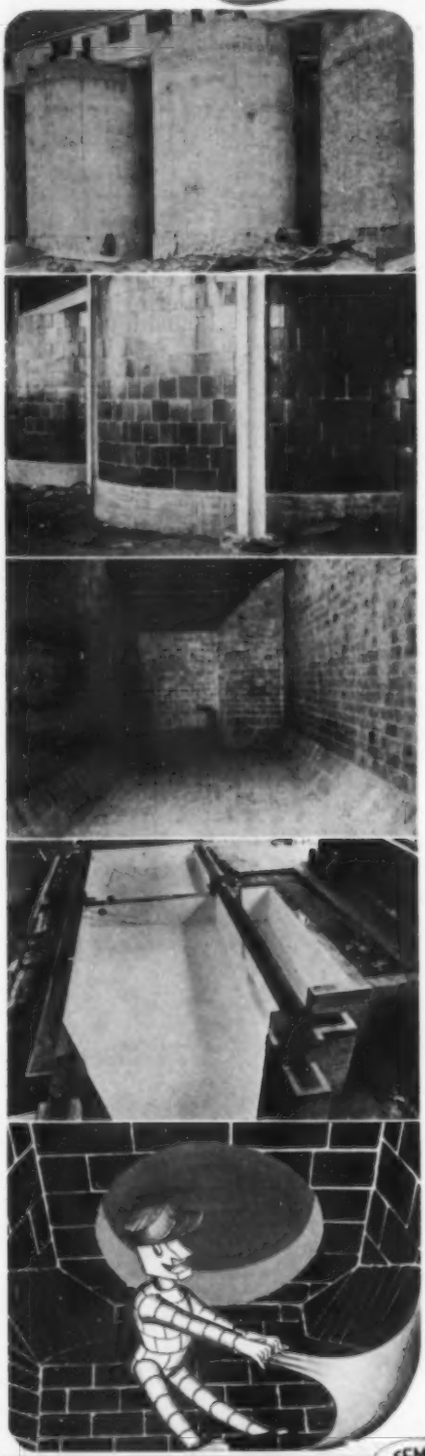

. . . . provide process plants wherever acids, alkalies, corrosive or non-corrosive liquids, gases or vapors are encountered, with an efficient, economical, long-lived and trouble-free installation.

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there were 26 bombings, and approximately 32 fires and explosions occurred on various steamers either at sea or in harbor.

Arson is one of the most common weapons used by the saboteur. It is frequently accomplished by: (a) substitution of highly flammable or explosive liquids for safer fluids used in the plant; (b) secreting of bombs in vital places in the plant; (c) setting of delayed fires.

In order to insure more complete destruction, the saboteur may attempt to cripple the fire protection facilities of the plant by: (a) damaging standpipes or hose for extinguishers; (b) substituting flammable liquids in extinguishers; (c) tampering with sprinkler valves; (d) tampering with fire alarm or watchmen systems.

The saboteur may even go further to insure destruction by attempting to handicap the fire department by: (a) damaging water supply sources or services; (b) interfering with fire alarm or telephone system; (c) sending in false alarms or starting fires at the same time at other parts of the plant; (d) damaging fire apparatus in the stations or on the fire grounds.

Each of the above points should be checked frequently by different personnel in the plant in order to insure safety from arson during the war emergency.

Compiled by J. W. Just, Maryland Fire Coordinator and Director of Fire Service Extension, College of Engineering, University of Maryland, College Park, Md.

DECONTAMINATION OF CHEMICAL WARFARE GASES

DECONTAMINATION METHODS to be used against the persistent chemical warfare gases are outlined in the following summary. Mustard gas, Lewisite and brombenzyl cyanide are the most common persistent war gases. These gases will remain in concentrations sufficient to cause casualties for three days in the open and seven days in woods.

Summarized Methods of Decontamination

Surface or Material	Method of Treatment
Roads	
Fine spray of gas on any surface	Hose down within 30 min. or leave to weather.
Heavy spray of blister gas on outer zone of bomb contamination on all surfaces	Hose down immediately for 10 min. Brush down pavement with bleaching powder and water.
Heavy contamination on:	
Stone paving and concrete surfaces	Brush bleach paste and water over surfaces and into joints. Leave for 15 min. and hose down thoroughly.
Wood paving.....	Hose down for 15 min. Allow bleach and sand in contact for 2 hours. Clean off and hose down.
Tar, Macadam, bitumen asphalt	Hose for 15 min. Use dry bleach. Road heating machines may be necessary.
Natural earth, grass, etc.	Cover with 3 in. fresh earth and leave to weather. If contamination is severe and near premises, add 25% bleaching powder to top layer of earth

Buildings	
Stone or brickwork	Hose down immediately. Brush in bleach paste. Leave in contact 24 hours. Hose down.
Tile or concrete floors	Hose down. Leave bleach paste in contact 10 hours. Hose down and apply sodium silicate solution diluted with 5 times as much water.
Glazed tiles	Hose down and leave bleach paste in joints 10 hours. Hose down.
Papered walls	Strip paper. Wash off with bleach paste, leave in contact 48 hours. Wash off and apply sodium silicate as above.
Painted surfaces	As for wall paper.
Wood floors, painted woodwork	Absorb liquid with dry earth, which should be buried. Scrub with bleach paste. Leave for 24 hours. Wash off and repeat. Remove and burn all boards soaked with liquid.
Hardwood polished surfaces	Swab with kerosene. Treat with bleach paste and vaseline. Leave in contact 24 hours. Wipe off and wash.
Upholstery	Strip off and burn.
Linoleum	Burn if worn and badly contaminated, otherwise use bleach paste and wash off.
Metalwork	Swab with kerosene or unleaded gasoline and rub dry.
China and glass	Treat in bleach solution and wash in hot water.
Rubber protective clothing	Hose off, apply bleach paste and wash. Boil rubber boots 2 hours.
Respirators	Dismantle, boil rubber parts 2 hours. Treat eyepieces and outside of container with bleach paste and vaseline for 10 hours. Boil haversack ½ hour.
Woolen clothing, blankets	
Vapor contamination	Air (in a safe location for one or two days).
Liquid contamination	Boil for ½ to 1 hour in plain water. Article must be completely immersed to minimize shrinkage and *no soap or washing compounds used.* Do not rub.
Cotton, linen and canvas articles	Boil for ½ to 1 hour in water containing about 2 oz. washing soda per 10 yards.
Boots, shoes, leather articles	Soak in cold water for 1 hour, then in warm water at about 125 deg. F. for 6 hours. Do not boil.
Rubber boots, etc.	Boil for 1 to 2 hours in plain water.
Oilskins, protective clothing	Soak for ½ hour in plain water at 200 deg. F. Do not boil. Articles must be handled carefully or oil film will be ruined.

If the articles have been contaminated with Lewisite, additional airing for one or two weeks may be necessary to remove the residual odor.

George L. McCoy, chemical engineer, before The Junto, Philadelphia's Adult School, 16 South 10th St., Philadelphia, Pa., March 13, 1942.

COMMERCIAL LEAD PLATING

LEAD HAS NOT been extensively electroplated because the low melting point of the metal (327 deg. C.) has made it possible to use a hot dipping process in which case the lead must be alloyed with 10-20 percent tin, since molten

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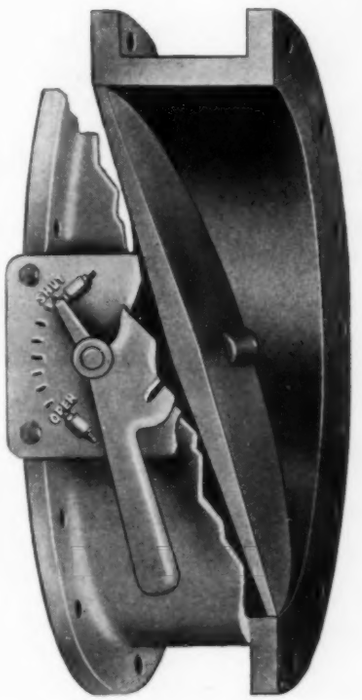

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lead does not adhere readily to iron. Recently, however, there has been a decided trend toward the use of electrodeposited lead in such applications as the protection of metals from corrosive liquids such as dilute H_2SO_4; lining of brine refrigerating tanks; plating of chemical apparatus; lining metal gas shells; barrel plating for nuts and bolts; plating storage battery parts; and plating apparatus used in the viscose industry.

The only two practical lead plating baths are the fluosilicate and the fluoborate. The former is standard in electrolytic lead refining; the latter is preferred in plating lead on steel and other metals. Although the fluoborate bath is more expensive than the fluosilicate, the lead deposits are finer grained and the bath is less susceptible to decomposition. For satisfactory protection of steel, the lead coating must be practically pinhole-free.

Fluosilicate plating has the following advantages and disadvantages: (1) it is difficult to prepare for small-scale plating operations as contrasted with lead refining; (2) the bath is subject to decomposition to give SiO_2 and lead fluoride; (3) it is cheaper for large-scale operations; (4) it will not plate directly on steel, requiring a preliminary coating of copper. Advantages and disadvantages of the fluoborate bath are as follows: (1) it gives finer-grained, denser deposits than the fluosilicate bath; (2) it is less susceptible to decomposition; (3) it is more expensive than the fluosilicate bath; (4) it gives a satisfactory plate directly on steel; (5) bath materials are very corrosive and require special precautions.

Composition of the fluoborate bath varies, depending largely on the current density required. For deposits up to about 0.001 in. thick produced in fairly low current densities, a bath of the following composition is recommended:

	Oz. per Gal.
Basic lead carbonate	20
50 percent hydrofluoric acid	32
Boric acid	14
Glue	0.025

For barrel plating operations or for still plating at higher current densities at which heavy deposits up to 0.05 in. thick are required, best results can be secured from a bath of the following composition:

	Oz. per Gal.
Basic lead carbonate	40
50 percent hydrofluoric acid	64
Boric acid	28
Glue	0.025

Fluosilicate baths recommended are as follows:

	Oz. per Gal.	Oz. per Gal.
Lead	10	24.0
Total fluosilicate	20	18.6
Glue	0.025	0.72

Allen G. Gray, research chemist, Electroplating Division, E. I. du Pont de Nemours & Co., Cleveland, Ohio, and William Blum, chemist, National Bureau of Standards, Washington, D. C., before the Electrochemical Society, Chicago, Ill., October 4, 1941.

SELECTIONS FROM FOREIGN LITERATURE

TREATED CELLULOSES

THE REACTIVITY of native cellulose can be greatly altered by such treatments as mercerization or solution and reprecipitation. For example, native cellulose in which the degree of polymerization is about 400 is insoluble in 10 percent caustic soda solution, but reprecipitated celluloses with degree of polymerization as high as 1,200 dissolve in this strength of caustic. Similarly, fibrous acetates formed by acetylating native cellulose in presence of pyridine are insoluble in organic solvents if degree of polymerization is above about 400, but if made in the same way from reprecipitated cellulose they will swell in organic solvents even when degree of polymerization is 2,000. Mercerized cellulose, which is essentially a hydrate, behaves much like native cellulose and yields acetates which behave like those from native cellulose. Its chief difference from native cellulose is in the nitration index, which is 1 for native cellulose and 0.5 for mercerized cellulose. Similar differences in behavior are observed with sulphite pulp and sulphate pulp, the cellulose of which differ substantially in certain aspects of reactivity. For nitration purposes and for the viscose process these differences are not barriers to use of cellulose from either source but for making cellulose acetate they must be considered with particular care.

Digest from "Deviations of Mercerized and Reprecipitated Celluloses From the Behavior of Native Cellulose," by H. Staudinger and R. Mohr, *Journal für praktische Chemie* **158**, 233-44, 1941. (Published in Germany.)

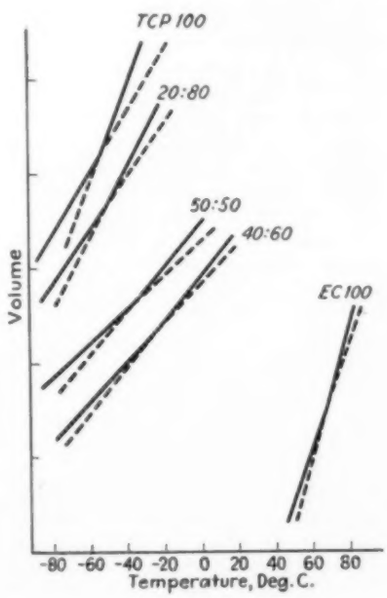
FIXED STRUCTURE LIQUIDS

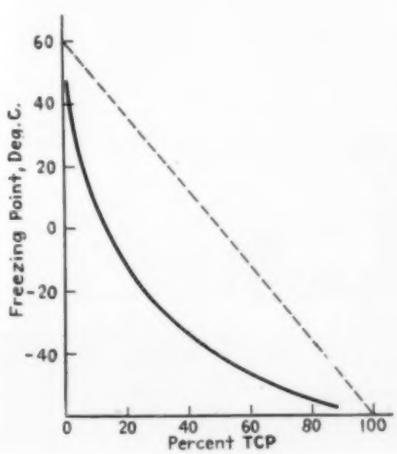
HIGH polymers such as cellulose, rubber (natural and synthetic) and polymer resins have been called "fixed structure liquids" because of their solidification behavior. The validity of the concept is supported by new evidence obtained in experiments with cellulose, cellulose hydrate, ethylcellulose and nitrocellulose. For example, films were cast from ethylcellulose (plasticized with tricresyl phosphate) in benzene solution. Films with plasticizer content up to 40 percent are highly elastic but strong. With 80 percent tricresyl phosphate the films are so soft that they flow under stress and have only slight elastic recovery, but they are not viscous liquids as are Bakelite resins with like plasticizer content. The effect of tricresyl phosphate in nitrocellulose is similar to that observed in ethylcellulose. Volume temperature curves are shown for pure ethylcellulose (EC), pure tricresyl phosphate (TCP) and their 60:40, 50:50 and 20:80 blends. These and the marked concavity of the accompanying freezing point curve illustrate the initially strong but progressively milder effect of added plasticizer on the mobility of molecular units in the system. The first few molecules of plasticizer greatly weaken the rigid linkage of chain units to each other in the pure high polymer, but increasing additions have less and less effect.

Digest from "Cellulose and its Derivatives as Fixed Structure Liquids," by Kurt Ueberreiter, *Zeitschrift für physikalische Chemie* **48B**, 197-218, 1941. (Published in Germany.)

PORCELAIN INSULATORS

PORCELAIN insulators for outdoor high voltage apparatus must perform under a wide variety of conditions without breakdown. In highly polluted or humid atmospheres the insulator should have a leakage path of 2 in. per kv. of applied current. Special antifog insulators prevent flashover under fog conditions. To anticipate such causes of irregular potential distribution a special insulator has been designed in which resistors are inserted to stabilize potential distribution. De-





Left—Volume-temperature curves for ethyl cellulose-tricresyl phosphate blends. Below —Freezing point curve for the EC:TCP blends

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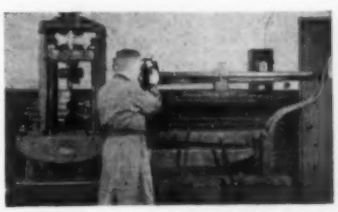

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terioration tests indicate that modern high quality insulators will not deteriorate at a faster rate than 0.1 percent per year. Nevertheless field tests must be made at intervals because a single faulty insulator may cause complete failure of an insulator line. A system of field testing is described which has been about 90 percent correct in diagnosis of faulty insulators. Radio interference by high voltage power transmission lines is much worse in fog than in fair weather, but the strength of the interfering field decreases rapidly with increasing distance from the high voltage line so that interference with local broadcasts practically disappears within about 50 yards even in foggy weather.

Digest from "Characteristics and Performance in Service of High Voltage Porcelain Insulators," by J. S. Forrest, *Journal of the Institution of Electrical Engineers* **89**, II, No. 7, 60–80, 1942; discussion, pp. 80–92. (Published in England.)

CALCIUM ARSENATE DISPERSIONS

AMMONIUM alginate is an effective protective colloid for calcium arsenate in fungicidal or insecticidal sprays. In experiments with commercial arsenate, ground with the protective colloid in a ball mill or in a colloid mill, it was found that sodium alginate is not satisfactory for use with calcium arsenate dispersions. Ammonium alginate was satisfactorily effective when prepared separately and added to the dispersion. It was much more effective, giving an excellent dispersion-stabilizing effect, when prepared in the calcium arsenate dispersion. Sedimentation was prevented for at least 48 hours in such dispersions. This is illustrated by viscometric data for dispersions when freshly prepared and when 48 hours old. The relative viscosities were measured in an Ostwald viscometer and refer to water as unity.

Ca Arsenate percent	Relative Viscosity	
	Fresh	After 48 hrs.
0.1	2.94	2.48
0.5	4.17	3.92
1.0	4.75	4.62
5.0	15.4	15.2

The optimum pH range for stability of these dispersions is on the alkaline side (due to excess calcium oxide) and is fairly wide, namely from 10.26 to 11.82.

Digest from "Properties of Alginic Acid. II. Ammonium Alginate as a Protective Colloid," by Yu. K. Novodranov and E. K. Smirnova, *Kolloidnyi Zhurnal* **7**, No. 1, 89-94, 1941. (Published in Russia.)

WASTE PICKLING LIQUOR

DISPOSAL of waste liquor from pickling iron and steel and disposal of waste sludge from lime-soda water softening plants are two problems which may be capable of a joint solution. The lime-soda sludge can generally be had for the cost of transportation. Hence it is much cheaper than other alkalis for neutralizing waste pickle liquor. Its alkalinity is not high enough for complete removal of ferrous sulphate from the pickle liquor but this can be remedied by adding sufficient soda ash

to raise pH to the required level. The method is not applicable if the effluent must be a clear solution unless the cost situation justifies evaporating the neutralized liquor to recover the solids. Another cheap waste alkali which might be used is slaked lime from conversion of calcium carbide to acetylene.

Digest from "A Suggested Method for Neutralizing Waste Pickling Acid Effluents," by F. Smith, *Chemistry and Industry* **61**, 68–9, 1942. (Published in England.)

HARDENING OF PHENOLIC RESINS

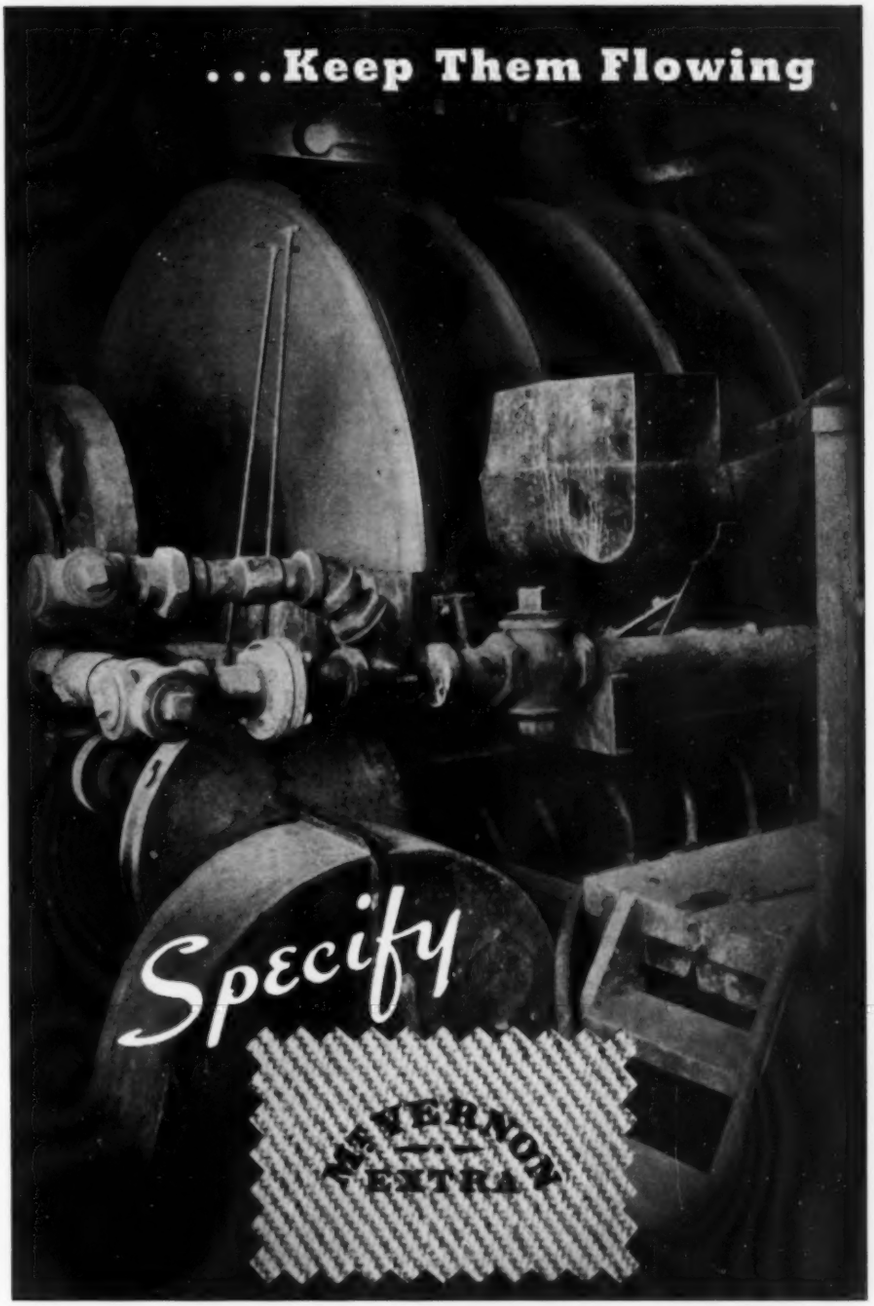
PREVIOUS work had shown that when para-substituted phenol dialcohols are heated the loss of water and formaldehyde is not concurrent and equal. At first only water is expelled from the molecule, while formaldehyde begins to come off at a definite temperature which depends on the structure of the dialcohol. This study has now been extended to ortho-substituted phenol dialcohols by quantitative pyrolysis experiments. Eight phenol dialcohols with ortho structure were investigated, in pairs derived respectively from *o*- and *p*-cresol, *o*- and *p*-cyclohexylphenol, *o*- and p-methoxyphenol and *o*- and *p*-chlorophenol.

As in the case of para-substituted dialcohols, occurrence of the corresponding dialdehydes was demonstrated qualitatively, but in this case the dialdehydes were too much contaminated with oily products to be isolated. It was found that *o*-cresol dialcohol evolves water and formaldehyde over a wider temperature range than the para compound, thus bringing out more plainly the stepwise course of the reaction. The experimental results also showed greater influence of para-substituents than of ortho-substituents on the reactions involved in hardening of phenolic resins. With this exception the reactions show little difference as between ortho and para compounds. The results support previous evidence that the first stage in hardening of a phenolic resin is successive joining of dialcohol molecules in a polyether chain.

Digest from "Study of the Hardening Process in Phenol-Formaldehyde Resins," by Franz Hanus, *Journal für praktische Chemie*, **158**, 245-53, 1941. Published in Germany.)

ULTRAFINE GRINDING OF STARCH

PROLONGED grinding of wheat starch in a ball mill destroys the organized microstructure of the granules and makes them permeable to cold water. After about 470 hr. most of the starch is soluble in cold water and in about 2,000 hr. the change is practically quantitative. The low phosphorus or phosphorus-free fraction of starch is most sensitive to grinding and is the first to be solubilized, but eventually the granules of the high phosphorus fraction are also disrupted. When grinding has been carried to the stage at which there is a considerable proportion of cold water soluble (CWS) and hot water soluble (HWS) fractions the phosphorus content of the CWS fraction (calculated at P_2O_5) is about 0.02 to



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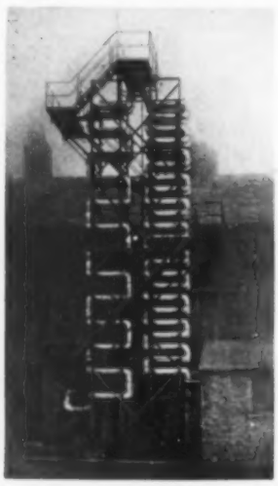

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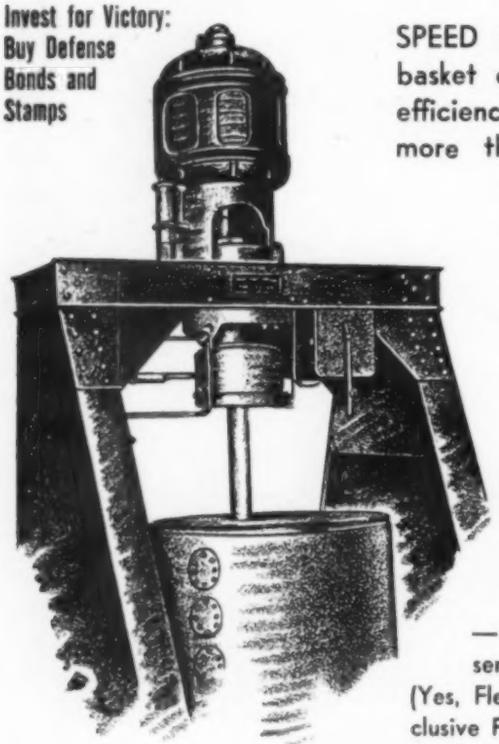

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0.08 percent while that of the HWS fraction is about 0.2 to 0.34 percent. Stated in other terms, the number of starch macromolecules per phosphorus atom is from 3 to 10 in the CWS fraction and less than unity in the HWS fraction. Another characteristic difference between the CWS and HWS fractions is their retrogradation behavior. When a 2 percent solution is aged for a week at 4 deg. C., less than 10 percent of the CWS fraction retrogrades whereas there is from 54 to 85 percent retrogradation in the HWS fraction. The retrograded starch is easily dissolved by heating its aqueous suspension to incipient boiling. These results are not necessarily applicable to other starches but probably represent the general behavior of cereal starches better than of root and tuber starches.

Digest from "Fractionation of Wheat Starch. IX. Summary and Discussion," by L. H. Lampitt, C. H. F. Fuller and N. Goldenberg, *Journal of the Society of Chemical Industry* **60**, 301-5T, 1941. Published in England.)

DESULPHURIZING WITH ACID SLAGS

CRUDE iron can be successfully desulphurized with acid slags in a graphite crucible. Sulphur is driven off as a vapor, in the form of a vaporizable silicon sulphide, SiS. The iron thus treated is practically sulphur-free. The silicon with which the sulphur combines is derived mainly from the slag, so that the iron retains approximately its original silicon content. The slag does not retain the sulphur taken from the iron since silicon monosulphide is volatile at the desulphurization temperature. The trials with crude iron indicate that steel can also be desulphurized by the same method, at appropriately higher temperatures. Six calcium-aluminum silicate slags were tested, beginning with a mildly basic slag with low desulphurizing capacity ($CaO:SiO_2$ ratio 1.2) and proceeding through lower $CaO:SiO_2$ ratios to a calcium-free aluminum silicate slag and finally to pure silica, which had the highest desulphurizing power of all.

Digest from "Desulphurizing With Acid Slags," by Robert Durrer, Heinrich Hellbrügge and Borut Marincek, *Archiv für das Eisenhüttenwesen* **14**, 527–32, 1941. (Published in Germany.)

COLLAPSIBLE TUBES

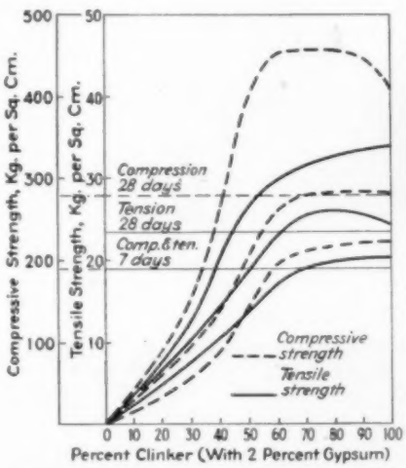
TINNED lead as a substitute for pure tin in collapsible tubes has its drawbacks, but lead is cheaper and less dependent on importations. The thickest coating of tin which can be applied (unler the rule restricting tinned lead tubes to 10 percent of the tin used in pure tin tubes) is about 280 mg. per 100 sq. cm. If properly applied this can give a fairly nonporous coating but photomicrographs indicate that cracks rather than pores are the chief defects on the tinned lead surface. If the paste packed in the tube is an electrolyte, corrosion quickly sets in if the tinning leaves any exposed lead. Thus, paste in a pure tin tube absorbed 6.5 mg. of tin per 100 g. whereas the

same paste in a tinned lead tube absorbed 26 mg. This is proof of electrolytic rather than chemical corrosion. In general tin is the anode and lead the cathode in such corrosion. Oxidative corrosion is responsible for the familiar staining and deterioration of pastes at the folded and nozzle ends of tinned lead tubes. Tubes for export must have pure tin nozzles even if made of tinned lead. Otherwise nozzle corrosion causes spoilage even with the best tinning. In this case 20 percent consumption of tin (as compared with pure tin tubes) will suffice.

Digest from "Tin-Coated Lead Tubes versus Pure Tin Tubes," by O. J. Bruun, *Perfumery and Essential Oil Record* **33**, No. 2, 57–9, 1942. (Published in England.)

EXTENDERS FOR CEMENT

PORTLAND cement can be made to accomplish more in construction by adding inert powdered materials when the service conditions do not demand the highest quality. In experimental trials Portland cement clinker containing 2 percent of gypsum was ground in a ball mill with limestone in the proportions 80:20, 70:30, 60:40, 50:50 and 40:60. Test specimens were made up with 3 parts sand to 1 part of the extended cement for measurements of crushing strength and tensile strength. There was no significant loss in strength until the proportion of inert ingredient



Strength of portland cement (with 2 percent added gypsum) mixed with various proportions of limestone.

reached about 30 to 35 percent (20 to 25 percent when sandstone was used instead of limestone). The lower limit of acceptable strength is reached at about 50 percent limestone (about 35 percent sandstone). Fineness of grinding is an influential factor; strength was higher for a cement ground to 900 mesh than for one ground to 6400 mesh, but cement ground to 4900 mesh gave stronger test pieces than the coarser and finer cements. The chart shows curves for compressive and tensile strengths of test pieces from cements made with increasing proportions of limestone.

Digest from "Adding Inert Powders to Portland Cement," by A. Vian, *Ion* **1**, No. 3, 14-18, 1941. (Published in Spain.)

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of
AMERICAN CHEMICAL INDUSTRY

★ Reprinted from *Chem. & Met.'s* February 1942 issue, wherein the editors presented a 40-page public accounting of the economic and technical status of the nation's most important industry. It is addressed to everybody because we are all stockholders, customers and/or employees in this billion dollar business that in 1941 topped all production records.

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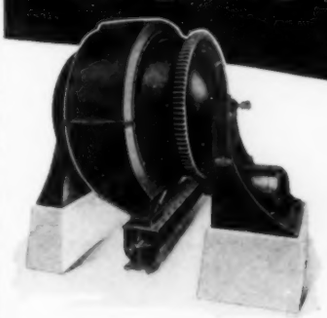

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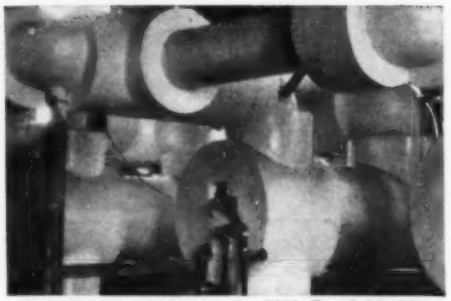

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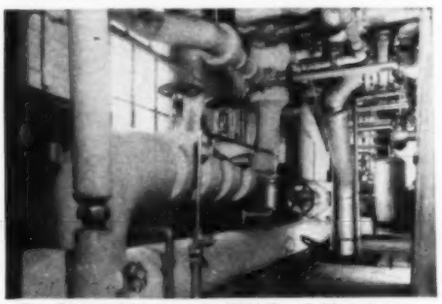

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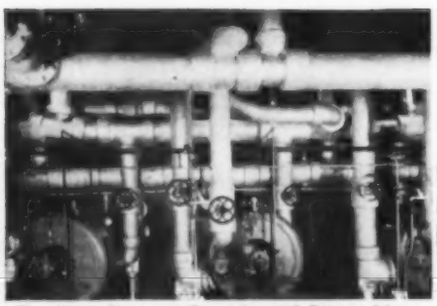

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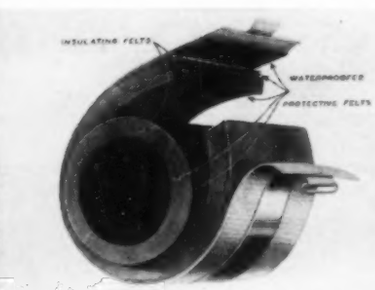

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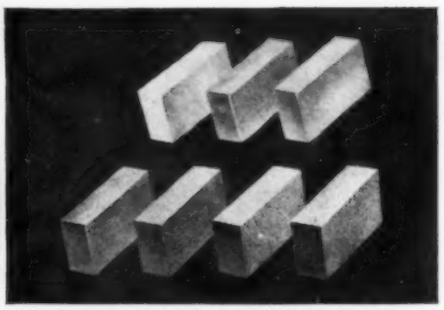

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MEMOIRS AND MIRACLES

THIS CHEMICAL AGE. By *Williams Haynes*. Published by Alfred A. Knopf, New York, N. Y. 385 pages. Price $3.50.

Reviewed by *S. D. Kirkpatrick*

HERESY though it be, here is one book that one reviewer read from cover to cover. And he enjoyed it and wanted more. Further, he admits that at first it was just part of an interesting game which this same reviewer had enjoyed on other occasions, namely, checking up a bit on the author's chemistry, hunting for picayune errors like getting his "methyls" and "ethyls" mixed up (as he did, for example, on p. 34). Then, later, after laboring just a little to plow through the first two schoolbookish chapters of "thoroughly unscientific over-simplification" (these words kindly supplied by the author himself), the skeptic began to realize that here was something worth reading and enjoying in its own right.

A truly fascinating book about the most modern chemical developments has at last been written in a way that almost anyone can understand and appreciate. The author's live, sprightly style, which sometimes used to irritate his less facile friends when he roasted them on the "We" page of *Chemical Industries*, now comes into good stead as he spins stories of subjects the layman might otherwise find dull, heavy and uninteresting. Always, too, there is evidence of careful research and uncanny ability to draw on the widest possible sources of historic as well as current information.

Its twenty chapters reveal different approaches to as many different branches of chemical industry. They run the range from peace to war, from dyes, medicinals, perfumery, cosmetics, plastics and paper, to the munitions and explosives that go to stock "Our Chemical Armory." And "If you want more," as will surely be the case with many readers, there is a brief bibliography followed by—of all things in a Knopf "best seller"—a six-page glossary of "Words that Puzzle."

Nothing very important, it seems, has been left out of this latest and best of the author's famous M-Series of masterpieces. They started back many years ago with "Modern Miracles" followed by "Men, Money and Molecules." This one carries the alliterative subtitle, "The Miracle of Man-Made Materials." May the master mind make many more as he grows mellower and merrier.

PROCEEDINGS OF AMERICAN GAS ASSOCIATION, 1941. Published by American Gas Association, New York, N. Y. 678 pages. Price $3 to members, $7 to non-members.

THIS is the large volume of proceedings of A.G.A. which summarizes all of the annual convention and much of the subsidiary material developed by the work of various sections during the year. The book represents the only printed record of technical papers and committee proceedings which is issued officially.

TIMELY NEW EDITION

CHEMICAL ENGINEERING PLANT DESIGN. Second edition. By *F. C. Vilbrandt*. Published by McGraw-Hill Book Co., New York, N. Y. 452 pages. Price $5.

Reviewed by *R. H. McCormack*

THE SECOND edition of Chemical Plant Design brings up to date one of the most helpful single books available for the teaching of this subject. The increased production demand of the war coupled with a great increase in relatively complicated synthetic processes make the design course more important than ever before in the Chemical Engineering curriculum. The revision of this standard text will, therefore, be welcomed both by teachers and by the future employers of their students. Dr. Vilbrandt pioneered in the establishment of a workable technique in the organization of such courses and the additions in the new edition round out his former satisfactory treatment of the subject.

The principal changes have been made in the chapters on Development and Plant Location. New tables, illustrations, and nomographs appear throughout the book. Enlarged lists of collateral readings have been added to each chapter. Considerably more emphasis has been placed on safety engineering, in line with modern engineering practice. There has been some rearrangement of the chapters to provide a somewhat more logical and unified treatment of the course.

Dr. Vilbrandt succeeds in the second edition, as in the first, in including sufficient material to make his presentation clear and avoids with admirable restraint the temptation to enlarge on the subject. The assumption is implicit that students will have sufficient preparation in drawing to handle the mechanical aspects of their design work, but enough material on drawing is included to review this subject and act as a reference guide in the preparation of such drawings as the course may require. The same type of treatment is given to structures, engineering materials, fluid flow and economics. These topics, and in fact, all but the material in the chapter "Development of the Design Project" are often covered in other courses in the chemical engineering curriculum. In this case, "Chemical Engineering Plant Design" becomes an extremely valuable summary of many courses integrated for the purpose of carrying out a design project. The various stages in the development of the design of a chemical plant are well illustrated and the role of the chemical engineer in such work is clearly defined.

To be complete, a text should include suitable student problems. These are grouped together in Appendices A, B, and C. The book is well furnished with illustrative problems indicating precisely the steps involved in the solution of design problems and projects.

LIQUID WASTE DISPOSAL

INDUSTRIAL WASTE TREATMENT PRACTICE. By *E. F. Eldridge*. Published by McGraw-Hill Book Co., New York, N. Y. 401 pages. Price $5.

Reviewed by *A. J. Fischer*

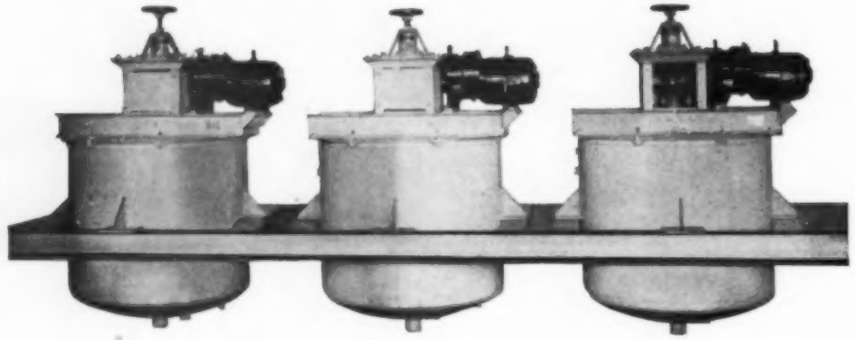
IN VIEW of the anticipated activity in industrial waste treatment after the war, this volume is timely. It is a first attempt in the United States to bring together information regarding the source, character and treatment methods of twelve general classifications of liquid wastes most commonly encountered in industry.

The need for abatement of industrial waste pollution is amply covered in the introduction and first chapter. Measurement, sampling, analyses and general characteristics of wastes are discussed in two additional chapters.

One chapter is devoted to standard methods of treatment and equipment employed in the treatment of domestic sewage as the same methods and equipment are also applicable to the treatment of industrial wastes. Unfortunately, however, some of the equipment described is now obsolete.

The main portion of the text deals with such specific types of materials as beet sugar, dairy, cannery, tannery, paper mill, textile, meat packing, laundry, heavy metal, phenol, distillery and oil wastes. The effect of these various types of wastes on the treatment of domestic sewage is also briefly discussed.

The chief value of this book lies in its description of the manufacturing processes involved in the various industries that produce liquid wastes. A substantial amount of data relating to the volume and character of most of these wastes are also presented. Information regarding the treatment of some types of wastes and processes is very meager, while over-emphasis has been given to some in which the author was most actively interested. This is understandable considering the fact that the author had to rely on avail-



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able published data for information on wastes other than those he encountered in the Michigan area. Such published data are widely scattered in the technical literature. Many fairly well known references containing considerable data were, however, not cited by the author.

Cost data are entirely lacking. It is hoped that this omission will be remedied in future revisions as such information would be of prime importance to plant officials contemplating waste treatment.

WOOD TECHNOLOGY. By *H. D. Tiemann*. Published by Pitman Publishing Corp., New York, N. Y. 308 pages. Price $3.50.

THIS is the first time an American author has attempted to incorporate under one cover a comprehensive review of the entire field of the technology of wood, anatomy, identification, description and properties of species, physiological botany, mechanics, physics, chemistry, pathology; and processes, as kiln drying, air seasoning, preservative, conversion, utilization, manufacture, distillation and pulping. No effort has been made to cover any phase of the subject thoroughly, on the contrary the author's aim has been to give a simple and clear perspective of all the various divisions and to leave specialization in any one to books devoted exclusively to that subject.

Mr. Tiemann has prepared the text for the use of the student in wood technology and the wood worker. He has endeavored to present the material in an accurate but not particularly technical manner in order that it may be understood by both technical and non-technical groups. Some of the information presented is new and will not be found in other books. It is profusely illustrated with photographs and photomicrographs.

EQUILIBRIUM AND KINETICS OF GAS REACTIONS. By *Robert N. Pease*. Published by Princeton University Press, Princeton, N. J. 236 pages. Price $3.75.

Reviewed by *Frederick C. Nachod*

DR. PEASE has prepared this text, which developed from a course of lectures, for "the reader who has been separated from academic work and who now wishes to catch up on recent developments in this important field of the interpretation of chemical processes."

As the title indicates, the book is divided into two main sections, namely; Chemical Equilibrium in Gaseous Systems, and Kinetics of Gas Reactions. This symbolizes the two methods of approach, static and dynamic, to the study of a system at equilibrium and to the study of the reaction rate as equilibrium is approached. The first part comprises chapters on thermodynamics and equilibrium, on the Nernst heat theorem and the third law of thermodynamics and on the quantum-statistical calculation of free energy. The second part contains chapters on

the quantum-statistical treatment of reaction rate, on reactions of simple order, on quasi-unimolecular reactions, on chain reactions, on gaseous oxidation reactions and on surface-catalyzed reactions.

The reader is made familiar with quantum-statistical methods (Chapters III and IV) which are explained thoroughly and applied to evidence given by various experiments. Two groups of reactions, where it is impossible to conceive equilibria (or pseudo-equilibria), do not lend themselves to complete quantum-mechanical treatment: quasi-unimolecular reactions and strongly exothermic oxidation reactions leading to explosions. Therefore only 20 pages are devoted to oxidation reactions in Chapter VIII which, however, presents a good cross-section of the work done in this field in the last 20 years.

At the beginning of each chapter appears a list of standard texts recommended to further study by the reader. Classical names like Lewis and Randall, Fowler, Tolman, Kassel, Hinshelwood, Semenoff, Bonhoeffer and Harteck, Jost, Schwab, and many others are found there. Aside from these citations, numerous references are given throughout the text. The printing and binding are excellent and no typographical errors were observed.

This is really an excellent book. Teachers, graduate students and men in the industrial field will equally enjoy studying this carefully prepared work.

MODERN PULP AND PAPER MAKING. Second Edition. By *G. S. Witham, Sr.* Published by Reinhold Publishing Corp., New York, N. Y. 705 pages. Price $6.75.

THE WORK on this second edition was almost complete when Mr. Witham died in June, 1939. His son, Mr. George S. Witham, Jr., himself a paper mill engineer, with the assistance of many of his father's friends, has completed the manuscript and made the book available.

The author's chief motive in writing the book was to give to young men in the pulp and paper industry the help that he would have been grateful for in his early days in the mill. It meets the requirements of those who want a general treatise of the industry in a single volume and written in the simplest, descriptive manner. Naturally it was impossible to be complete in details, such as was done in the five-volume series prepared by TAPPI and the Canadian Technical Section.

This second edition has been completely revised. The chapters have been rearranged in more logical order. A chapter has been added on modern converting and coating practices. The finishing room has been given considerably more space. The chapter dealing with bleaching has necessarily been greatly expanded in order to cover discussion of the new methods that have been developed in recent years. Among the subjects covered in this new edition

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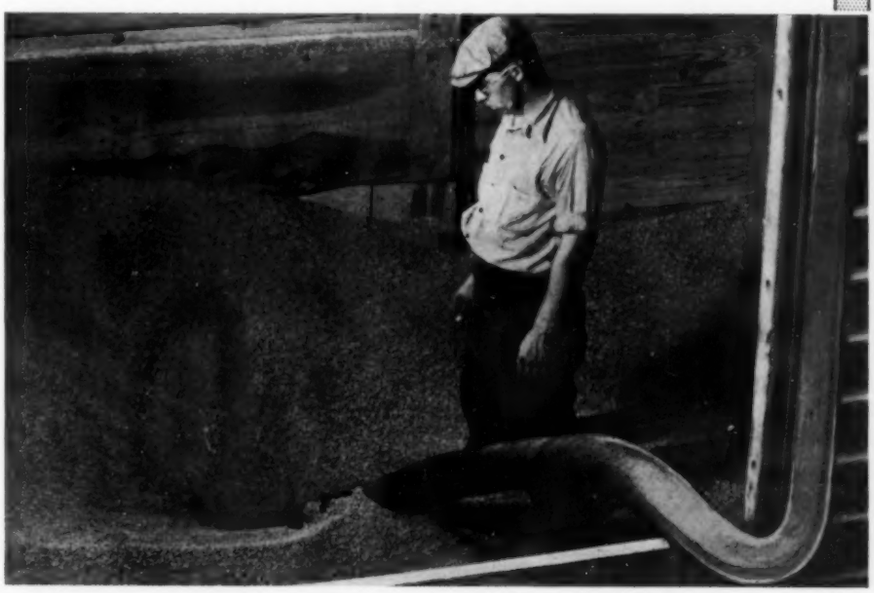

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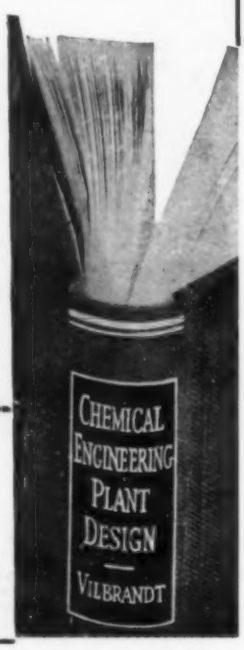

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FLUORESCENT CHEMICALS AND THEIR APPLICATIONS. By *Jack DeMent*. Published by the Chemical Publishing Co., Brooklyn, N. Y. 240 pages. Price $4.25.

IT IS the object of the author, who is a chemist with The Mineralogist Laboratories and associate editor of *The Mineralogist Magazine*, to tabulate in the present volume the greater number of the known fluorescent substances. Nearly 3,000 such chemicals have been listed. In addition, there are chapters which deal with the sources of ultraviolet light, technique of observing fluorescence and the applications of fluorescent chemicals. The book, intended primarily for the research chemist, is well and interestingly written. However, it is doubtful if the information would be of much value to practicing engineers. Both binding and typography are good, but the work would probably find wider circulation and usage if the price were somewhat lower.

INDUSTRIAL ACCOUNTING. By *S. W. Specthrie*. Published by Prentice-Hall, New York, N. Y. 243 pages. Price $3.75 (trade), $3.25 (school).

TEXTBOOK for engineers, engineering students, and industrial and business executives, this volume presents the principles of industrial accounting clearly and concisely. The material is divided into three parts which cover basic accounting principles and bookkeeping procedures, accounting theory and practice, and executive use of accounting data. The author, a member of the faculty of Northwestern University, has reduced the details of accounting to readily understandable form and his presentation is greatly aided by numerous illustrative balance sheets.

MODERN PLYWOOD. By *Thomas D. Perry*. Published by Pitman Publishing Co., New York, N. Y. 366 pages. Price $4.50.

THE DEVELOPMENT of the synthetic resin adhesives has made a great change in the plywood industry, in fact so drastic has been the effect that it has been necessary to make a realignment of factory procedure. Likewise it calls for a revision of the literature on the subject, so that the manufacturer, the consumer and the engineer can take advantage of the technique.

It has been the aim of the author to delineate, clearly and briefly, the earlier technique, which still has a definite place in the industry. It was equally necessary to describe and compare the new technique, which is encouraging the extension of the use of plywood into many fields where its use formerly has been restricted. The new technique also is opening up new fields

for plywood, where the durability characteristics of resin-bonded plywood add distinct advantages to the many attributes which have made plywood increasingly useful in a wide range of wood products. The inertness of the synthetic resin adhesives and the strength of plywood offer the chemical industries what may be considered a new material of construction. Already some plywood vessels made by the new technique are being successfully used in the process industries.

The adhesives manufacturer will find of interest the chapter dealing with the various types of glues and adhesives, animal, vegetable, casein, soybean, blood albumin and synthetic resin.

THE CHEMICAL FORMULARY, VOL. V. Edited by *H. Bennett*. Published by Chemical Publishing Co., Brooklyn, N. Y. 676 pages. Price $6.

Reviewed by *John R. M. Klotz*

VOLUME V of the Chemical Formulary has come to hand and the Chemical Publishing Co. has scored again. The compilers of this very useful volume can have only one reward in the number of purchasers that develop for it, as it is indeed a very useful compendium.

It is the writer's personal regret that more of the colleges do not make use of such volumes as text books to let some of the first and second year students see the commercial applicability of chemistry. At one time or another in hiring men I have discovered many of them have been confused in the mathematical maze in attempting to unravel the mysteries of organic chemistry where nothing but simple facts were involved. I find many of them still remain in a daze even though they graduate and qualify as holders of a degree.

This is an enormously useful volume and experienced chemists as well as beginners can well apply themselves to seeing the development of formulations in the recent past. I recommend this book as well worth the price of admission.

IDENTIFICATION OF PURE ORGANIC COMPOUNDS. By *Ernest H. Huntress* and *Samuel P. Mulliken*. Published by John Wiley & Sons, New York, N. Y. 691 pages. Price $7.50.

SUBTITLE to this volume, in which 1,364 compounds are listed, is "Tables of Data on Selected Compounds of Order I." For those of us who need reminding, Order I comprises the compounds of carbon and hydrogen or carbon, hydrogen and oxygen. It is divided into two suborders, I and II (colorless and colored compounds).

The whole scheme of analysis is based on a series of tests which place a compound of suborder I into one of nine genus groups. Further classification, where necessary, gives divisions and sections. After locating order, suborder, genus and section, reference is made to the tables of data which comprise the major portion of this book.

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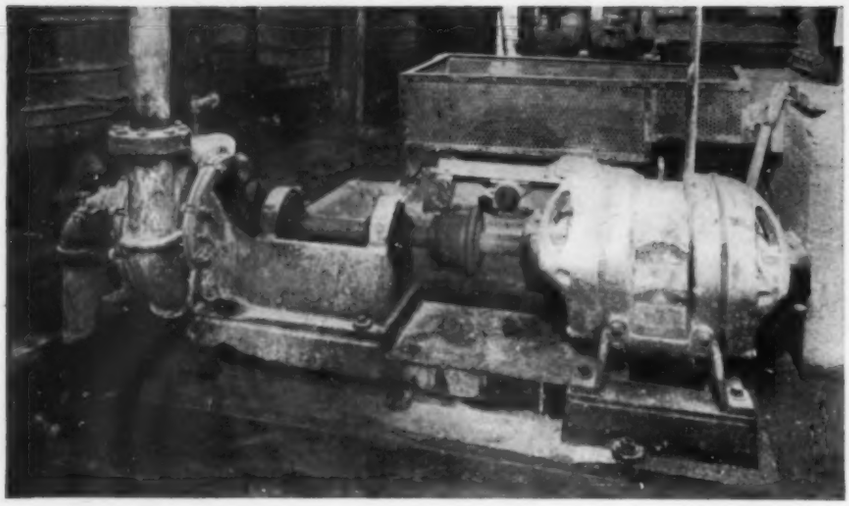

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Tables of melting points of derivatives, an index according to empirical formula and an alphabetical index are included in the book. It is truly a monumental work which will surely find its way onto the reference shelves of hundreds of laboratories and libraries.

RECENT BOOKS and PAMPHLETS

Manganese Resources of East Tennessee. By *Stanley O. Reichert*, edited by *Geo. L. Whitlatch*. Published by State of Tennessee, Division of Geology, Nashville, Tenn. 212 pages. Price 25 cents. Covers both geology of the ore occurrence, methods for large-scale prospecting and milling activities in the area, which in 1940 had the largest output of ferro-grade manganese in the United States. Past mining failures in these manganese fields have been mostly due to lack of scientific prospecting, mining and milling.

Flax and Its Products. By *Warren E. Emley*. Published by The Textile Foundation, New York, N. Y. 30 pages. Price 10 cents. The status of the domestic flax and linen industry is brought up-to-date by discussing the flax plant, the flax fiber, preparation of the fiber, coarse and fine linen, the Oregon flax industry, decortication, rugs and towels, paper, substitutes, and the possibilities of developing an American linen industry.

Tour of Industrial Exploration. Published by the National Research Council, Washington, D. C. 102 pages. A condensation and segregation by topics of reports made by the 21 members appointed to visit six South American countries to observe and study industrial progress as well as "to exchange ideas, give advice and establish an enduring association."

Paper—the Lifeblood of Civilization. By *R. A. Hayward*. Published by the Technical Association of the Pulp and Paper Industry, New York, N. Y. 21 pages. Price 10 cents. A public relations job undertaken to help executives to minimize the labor turnover in the pulp and paper industry. Will give employees a picture of the part they are playing in the war program.

Symposium on the New Methods for Particle Sized Determination in the Subsieve Range. Published by the American Society for Testing Materials, Philadelphia, Pa. 111 pages. Price $1.25. Eight technical papers covering new methods for particle size determination. A number of these papers include extensive bibliographies.

War Gases, Incendiaries, Infernal Machines, Sabotage and Fire Fighting as Applied to Military Explosives and Ammunition. Material coordinated and compiled by *J. W. Just*, State Fire Coordinator and Director, University of Maryland, College Park, Md. 148 pages. A brief manual for instructors to be used in training firemen, auxiliary firemen and civilian groups in protection from enemy air raids, incendiary bombs, war gases, bombs, sabotage and fires. Contains excellent authoritative material in easily understandable outline form. Contains a list of instructors' review questions.

Digest of State and Federal Labor Legislation. Published by the Division of Labor Standards, U. S. Department of Labor, Washington, D. C. 50 pages. Gratis. Bulletin No. 48, representing the seventh annual publication of the kind. Summarizes the text of laws enacted by the 43 State legislatures which were in

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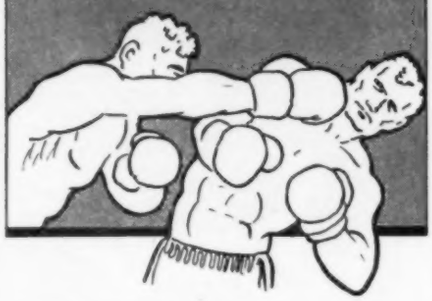

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session in 1941, as well as the legislatures in Alaska, Hawaii and Puerto Rico, and by the United States Congress.

Directory of Commercial Testing and College Research Laboratories. Miscellaneous Publication M-171 of the U. S. Department of Commerce. Obtainable from the Superintendent of Documents, Washington, D. C. 63 pages. Price 15 cents. Contains the names of 244 commercial laboratories, with 71 branch laboratories or offices, together with the addresses and a brief outline of the type of commodities or products tested. It also lists the laboratories of 199 colleges which are used not only for purposes of instruction but also to a considerable extent for research.

Symposium on Problems and Practice in Determining Steam Purity by Conductivity Methods. Published by the American Society for Testing Materials, Philadelphia, Pa. 80 Pages. Price 60 cents. A reprinting of a series of contributions dealing with such topics as sampling of steam and boiler water, experimental methods of determining conductivity correction for dissolved gases in steam condensate, calculation of corrections to conductivity measurements for dissolved gases, methods and apparatus available for the elimination from steam samples of gaseous impurities that affect conductivity measurements, and a new kind of conductivity apparatus for use with boiler waters and steam samples. There are also included a general discussion on conductivity cells and electrical measuring instruments, a combined bibliography on steam purity, and an introduction in which the significance of each contribution is pointed out.

Plastics Digest. Published by Plastics Publishing Co., New Brunswick, N. J. A new monthly digest service in periodical form covering the entire field of plastics and related subjects. The January 1942 issue appears as Vol. I, No. 1. Price $20 per year.

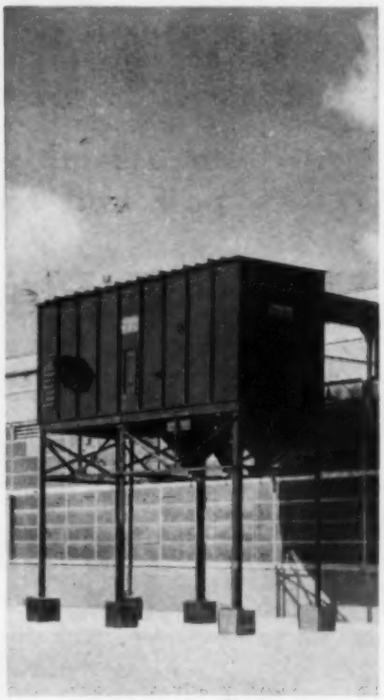
British Plastics Yearbook, 1942. Published by Plastics Press, Ltd., London. 464 pages. Price 15s. The usual excellent quality of paper and printing will be found in this annual edition. Changes in advertisements and editorial content are of a minor nature.

Credit Problems in a War Economy. By *R. A. Foulke.* Published by Dun & Bradstreet, New York, N. Y. 71 pages. Issued as a supplement to Foulke's study of ratios, "Behind the Scenes of Business," this booklet discusses the problems of both the war product and the non-war product manufacturer. The discussion occupies half the booklet and is an introduction to a series of tables giving "Fourteen Important Ratios With Interquartile Range for 72 Lines of Business Activity" and "Comparative Ratios for the Years 1936-1940." Both sets of tables include a heading of manufacturers of industrial chemicals.

Resins, Rubbers, Plastics. A loose-leaf abstract service. Edited by *H. Mark* and *E. S. Proskauer.* Published by Interscience Publishers, Inc., 215 Fourth Ave., New York, N. Y. Subscription price $35 per year. An abstract service devoted to synthetic resins, rubbers and plastics, including scientific aspects of cellulose and fiber chemistry. The first issue (33 pages) contains table of contents of the service and abstracts of January issues of technical periodicals. Abstracts are quite comprehensive and contain most data and facts of original papers, reproduce important graphs, frequently making consultation of original literature unnecessary. The publisher's estimate that between 500 and 600 pages will be supplied during 1942.

A.S.T.M. Standards on Copper and Copper Alloys. Published by the American Society for Testing Materials. 350 pages. Price $2. Copper and copper alloys in cast and wrought form, as used for electrical conductors. Gives requirements for non-ferrous metals used in copper alloys. There are 73 standards covering a variety of products, many of which are essential in the present national emergency program.

Airplane Metal Work. By *A. M. Robson.* Published by D. Van Nostrand Co., New York, N. Y. Volumes 4 and 5 of this series of books have recently been published. Vol. 4, 103 pages, deals with pneumatic riveting of airplane structures. Vol. 5, 94 pages, is a manual of instruction for sheet metal repair and describes methods of patching or otherwise making serviceable planes and parts which have been damaged. Prices are $1.25 each.



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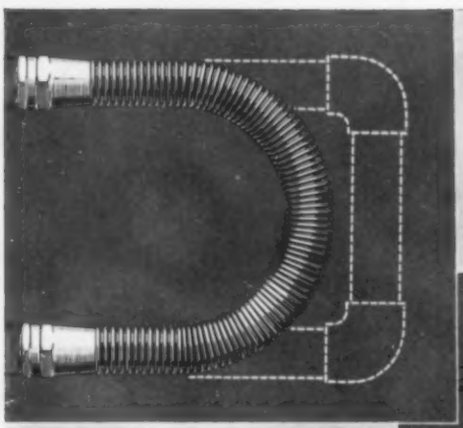

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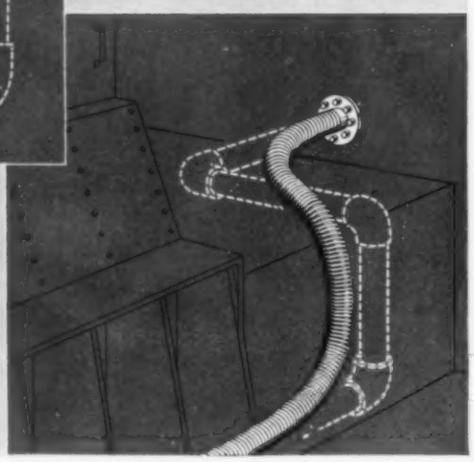

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GOVERNMENT PUBLICATIONS

The following recently issued documents are available at prices indicated from Superintendent of Documents, Government Printing Office, Washington, D. C. In ordering publications noted in this list always give complete title and the issuing office. Remittances should be made by postal money order, express order, coupons, or check. Do not send postage stamps. All publications are in paper cover unless otherwise specified. When no price is indicated, pamphlet is free and should be ordered from Bureau responsible for its issue.

Ore-Testing Studies of the Ore-Dressing Section, Fiscal Year 1941, by A. L. Engel and S. M. Shelton. Bureau of Mines, Report of Investigations 3628. Mimeographed.

Damage from Air Blast, by S. L. Windes. Bureau of Mines, Report of Investigations 3622. Mimeographed.

Limits of Inflammability and Ignition Temperature of Styrene in Air, by G. W. Jones, G. S. Scott, and W. E. Miller. Bureau of Mines, Report of Investigations 3630. Mimeographed.

Methanol Poisoning. 1. Exposure of Dogs to 450-500 P.P.M. Methanol Vapor in Air, by R. R. Sayers, W. P. Yant, et al. Bureau of Mines, Report of Investigations 3617. Mimeographed.

Biennial Report of Petroleum and Natural-Gas Division. Fiscal Years 1940 and 1941, by R. A. Cattell, G. B. Shea, and others. Bureau of Mines, Report of Investigations 3616. Mimeographed.

Manganese Investigations. Bureau of Mines has issued several documents on manganese investigations, recent mimeographed pamphlets of this series are: Concentration of Manganese Nodules from Chamberlain, S. Dak. Report of Investigations 3616. Concentration of Manganese-Bearing Ore from the Dobbins Mine of Cartersville, Ga. Report of Investigations 3613. Concentration of Manganese Wad Ores from the Chinn Property, Batesville, Ark. Report of Investigations 3614. Concentration of Manganese Ores from the Little Florida Mountains, Luna County, N. Mex. Report of Investigations 3620. Nitrogen Dioxide Process for Recovery of Manganese from Ores. Report of Investigations 3626. Sintering or Nodulizing of Ferrograde Manganese Mill Products and Fine Ores for Smelting Purposes. Report of Investigations 3625. Concentration of Manganiferous Iron Ore from the Armour No. 1 Mine, Ironton, Minn. Report of Investigations 3624. Concentration of Manganese-Bearing Ore from the Interstate Manganese Co., Johnson County, Tenn. Report of Investigations 3623.

The Legendary "White Metal" and its "Ore." by C. W. Davis. Bureau of Mines, Information Circular 7205 (revision of I.C. 6000). Mimeographed.

Annual Report of the Explosives Division, Fiscal Year 1941. By Wilbert J. Huff. Bureau of Mines Report of Investigations 3602; mimeographed.

Selection of Coals for Coke Making, by Joseph D. Davis. Bureau of Mines Report of Investigations 3601; mimeographed.

Collecting and Examining Subsurface Samples of Petroleum. By Peter Grandone and Alton B. Cook. Bureau of Mines Technical Paper 629. Price, 20 cents.

Novel First-Aid Instructors Association, by Albert A. Munsch. Bureau of Mines, Information Circular 7201. Mimeographed.

Some Suggestions on the Safe Use of Refrigerants, by H. H. Schrenk. Bureau of Mines, Information Circular 7199. Mimeographed.

Coke-Oven Accidents in the United States During the Calendar Year 1940, by W. W. Adams and V. E. Wrenn. Bureau of Mines, Technical Paper 640. Price, 5 cents.

Intercrystalline Cracking of Boiler Steel and its Prevention, by W. C. Schroeder and A. A. Berk. Bureau of Mines, Bulletin 443. Price, 15 cents.

Quicksilver Deposits in the Steens and Pueblo Mountains, Southern Oregon. Department of the Interior, Geological Survey, Bulletin 931-J.

Nickel Deposit near Gold Hill, Boulder County, Colorado. Geological Survey Bulletin 931-0. Price, 30 cents.

American Standard Specification for Dry Cells and Batteries. Bureau of Standards, Circular 435. Price, 10 cents.

Man-Hour Statistics for 171 Selected Industries. Prepared by joint collaboration of Bureau of the Census and Bureau of Labor Statistics. Mimeographed.

Control of Insects Attacking Grain in Farm Storage, by R. T. Cotton. Department of Agriculture, Farmers' Bulletin No. 1811. Price, 10 cents.

Insecticidal Efficiency of Some Oils of Plant Origin, by A. W. Cressman, Lynn H. Dawsey. Department of Agriculture, Technical Bulletin No. 801. Price, 5 cents.

Classification of House and Barn Paints, as recommended by the United States Department of Agriculture. Department of Agriculture, Technical Bulletin 804. Price, 10 cents. Describes a system of classifying paints by groups, types, and grades.

Explosives and Demolitions. War Department, Engineer Field Manual FM 5-25. Price, 25 cents.

Industrial Injuries Among the Urban Population as Recorded in the National Health Survey, by Joan Klebba. Public Health Service, Reprint No. 2339 from the Public Health Reports. Price, 5 cents.

Latin American Foreign Trade. A General Survey. Foreign Trade Series No. 193. Pan American Union. Price, 5 cents.

Our Public Works Experience. National Resources Planning Board, unnumbered pamphlet. Price, 10 cents.

After the War—Full Employment, by Alvin H. Hansen. National Resources Planning Board, unnumbered pamphlet. Price, 5 cents.

Soap Specifications. The following Federal soap specifications may be obtained from the Superintendent of Documents, Government Printing Office, Washington, D. C., at 5 cents each: Soap, Toilet; Milled, P-S-621a. Soap; Salt-Water, P-S-611a. Soap; Toilet, Powdered, (For) Dispensers, P-S-626a. Soap-Borax-Compound; Toilet (For) Dispensers, P-S-628. Soap; Laundry, Powdered, P-S-596a. Soap Powder, P-S-606a. Powder; scouring, (for) highly polished glass, P-P-596a. Soap; chip, P-S-566a. Soap; grit, cake, P-S-571a. Soap; Laundry, ordinary, bar, P-S-591a. Soap; toilet, liquid, P-S-618a.

Emergency Specifications. Numerous Government specifications are being amended to save scarce or strategic materials. Each of these is identified as in the usual Federal Specification with a large E preceding. Two recent examples are: E-RR-D-761, Steel drums and pails, I.C.C. type 5E, 5 gallon, single-trip-container. E-TT-W-261a, Basic-sulfate white lead, dry and paste-in-oil. Those requiring emergency specifications can be supplied with single mimeographed copies by Federal Catalog Division, Treasury Department, Procurement Division Building, Washington, D. C.

Production of Explosives in the United States During the Calendar Year 1940, by W. W. Adams, V. E. Wrenn, and L. S. Horton. Bureau of Mines, Technical Paper 636. Price, 10 cents.

Index of Coals Tested in the Bureau of Mines Survey of Carbonizing Properties of American Coals, by James E. Wilson and Joseph D. Davis. Bureau of Mines, Technical Paper 637. Price, 5 cents.

Cost of Living Studies. A series of studies of consumer purchases in urban, village, and rural areas has been made by the Department of Agriculture. A number of reports of the series are now available for those requiring information of this character, as follows: Family Expenditures for Clothing, Department of Agriculture, Miscellaneous Publication 422, Price, 35 cents. Family Food Consumption and Dietary Levels, Department of Agriculture, Miscellaneous Publication 452, Price, 30 cents. Family Expenditures for Housing and Household Operation, Department of Agriculture, Miscellaneous Publication 457, Price, 25 cents. Changes in Assets and Liabilities of Families, Department of Agriculture, Miscellaneous Publication 464, Price 25 cents.

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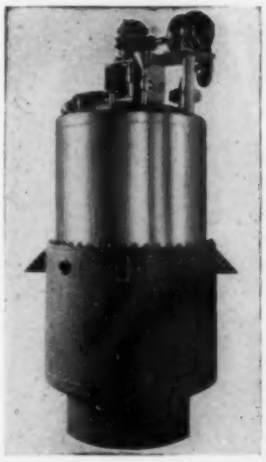

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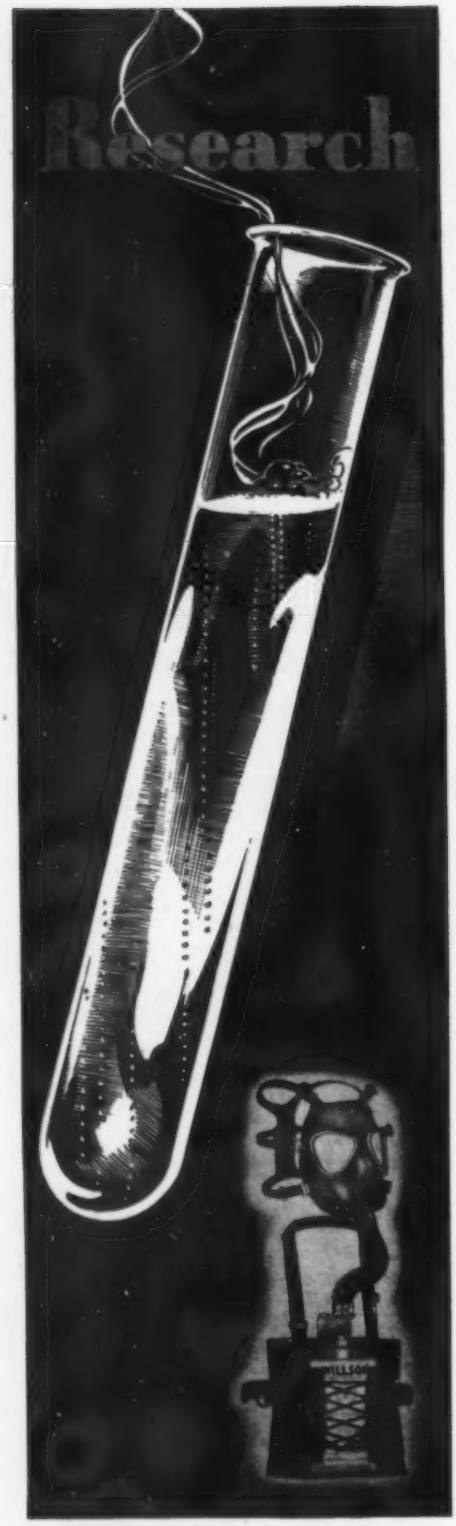

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MANUFACTURERS' LATEST PUBLICATIONS

Publications listed here are available from the manufacturers themselves, without cost unless a price is specifically mentioned. To limit the circulation of their literature to responsible engineers, production men and industrial executives, manufacturers usually specify that requests be made on business letterhead.

Asphalt Products. Keystone Asphalt Products Co., 43 E. Ohio St., Chicago, Ill.—New data sheet on the asphalt board put out by this concern which gives information on use of the product in building applications. Properties described include the board's resistance to water, acids, mildew, vapors, termites, etc.

Boiler Room Practice. Bailey Meter Co., 1070 Ivanhoe Road, Cleveland, Ohio —Bulletin 16—20-page publication entitled "How to Safely Stretch Steaming Capacity" intended as an aid to power engineers faced with the necessity of meeting sharply increased steam demands. Explains use of metering and control equipment. Illustrated by photographs and drawings.

Carbon Black. Godfrey L. Cabot, Inc., Technical Department, Boston, Mass.—24-page booklet on this concern's carbon black entitled "Spheron in Reclaim Tread Stock". Gives information on compounding procedure and detail results of a study on abrasion, flex cracking, plasticity and conductivity at various "Spheron" loadings. Data are summarized in table form. Extensively illustrated with charts.

Carburizers. Hevi Duty Electric Co., Milwaukee, Wis.—Bulletin HD142—24-page enlarged and revised edition of this concern's bulletin on its "Hevi Duty" carburizer. Discusses gas carburizing, construction of the unit, gas circulation, penetration, economies, operating costs, nitriding, etc. Contains photographs of various installations, cross-sectional drawings and specifications.

Chemical Stoneware. The United States Stoneware Co., 60 E. 42nd St., New York, N. Y.—Bulletin 550—12-page folder on the acid-proof pipe and fittings put out by this concern. Contains information on chemical analysis and physical properties, engineering and technical data, installation, and caulking compounds. The various kinds of pipe, pipe fittings, traps, tanks, etc., are illustrated by diagrammatic drawings. Specifications are given in table form.

Chemicals. Shell Chemical Co., San Francisco, Calif.—56-page second edition of this concern's booklet entitled "Organic Chemicals." Gives specifications, physical properties, shipping and container requirements, and uses of the organic chemicals at present manufactured on a commercial scale by this concern. Includes acetone, allyl alcohol nd chloride, butadiene, butyl acetate and alcohols, methyl ethyl ketone, and others. Also contains charts on properties of pure organic compounds and lacquer solvent data. Attractively and substantially bound.

Cleaning Compounds. Fidelity Chemical Products Corp., 430 Riverside Ave., Newark, N. J.—30-page booklet listing and describing briefly the properties and uses of this concern's complete line of metal cleaning, degreasing and stripping compounds. Also contains tables for finding capacities of tanks, weights and measures, etc.

Colloid Mills. The Manton-Gaulin Mfg. Co., Inc., 7 Charlton St., Everett, Mass. —Bulletin 32C—12-page pamphlet on the laboratory homogenizer and 2-stage colloid mill put out by this concern. Describes outstanding features of the units, specifications, capacity, dimensions and weight, and industrial uses. Illustrated.

Compressing Machines. F. J. Stokes Machine Co., Tabor Road, Olney P. O., Philadelphia, Pa.—Catalog 41T—44 page publication illustrating and describing the line of industrial tablet compressing machines put out by this concern. Includes information on uses of the machines in the chemical, pharmaceutical, ceramics and other industries. Contains specifications, photographs, descriptions and other information on each of the various models.

Compressors. Worthington Pump & Machinery Corp., Harrison, N. J.—Bulletin L675B1—28-page booklet on this concern's feather valve compressors ranging from 75 to 3,000 hp. Contains information on the feather valve, cylinder design, intercoolers, variable capacity control, auxiliary equipment, etc. Extensively illustrated by photographs and diagrammatic drawings.

Control Instruments. General Controls Co., 801 Allen Ave., Glendale, Calif. —Catalog 51—50-page catalog on this concern's complete line of regulators, control systems, and solenoid valves. Contains information on new products introduced by the concern. Contains photographs, reproduced blueprints, and cross-sectional drawings, together with specifications, list prices and data on pressure, temperature and flow controls for gas, air, oil, steam, etc.

Control Instruments. Moore Products Co., H and Lycoming Sts., Philadelphia, Pa.—4-page folder announcing this concern's new pneumatic differential pressure transmitter for indicating, recording and controlling meters. Briefly describes the unit, its principle of operation, construction, applications and price. Illustrated.

Defibrator. American Defibrator, Inc., 122 E. 42nd St., New York, N. Y.—Catalog 2—16-page folder dealing with this concern's "Asplund" defibrator for production of fiber from chips in one continuous operation. Describes the machine and process, its use, advantages, method of operating, construction, and other similar information. Contains numerous photographs and drawings.

Dust Collectors. American Foundry Equipment Co., Mishawaka, Ind.—Booklet 82—20-page booklet dealing with this concern's cyclone dust collector. Contains a discussion of the dust control problem, operating principles of the cyclone dust collector, mechanical features and construction, specifications, and other engineering data. Contains extensive data in tables, charts, and diagrammatic drawings. Also catalog 72, giving similar information on the concern's "Dustube" dust collectors of the knocked-down and assembled types.

Electrical Equipment. Westinghouse Electric & Mfg. Co., East Pittsburgh, Pa.—Booklet B3013—34-page booklet describing electrical instruments for industrial, central station, laboratory and general use, and portable switchboard and miniature panel instruments. Contains information on special features, specifications, and full-scale range of standard ratings. Extensively illustrated. Also Data Sheet 10-700, describing the manual auto-starters put out by this concern. Illustrated with wiring diagrams and close-up views of principal parts and contains a list of recommended starter sizes for common horsepower and voltage ratings of motors used on 25-60 cycle circuits.

Electric Motors. Westinghouse Electric & Mfg. Co., East Pittsburgh, Pa.—Form SA714—Pocket size "slide rule" selector for electricians, plant maintenance men and others interested in selection of electric drive equipment. Lists the various uses and indicates which of the four principal types of a.c. motors should be selected. Specifications, performance rating and control classes for the required type are determined by making the corresponding setting on the slide. Sturdy construction.

Fine Chemicals. Seydel Chemical Co., 225 Mercer St., Jersey City, N. J.—20-page booklet which describes briefly properties, grades and various uses of the fine chemicals put out by this concern. Includes benzoates for food, beverage and drug industries, benzyl compounds, ephedrine derivatives, and other similar products.

Gas Turbines. Allis-Chalmers Mfg. Co., Milwaukee, Wis.—Bulletin R6213—24-page booklet entitled "Keeping in Touch with Current Trends in Power Plant Development—The Gas Turbine" designed to give latest data and techni-

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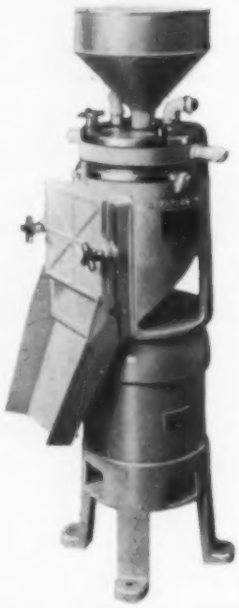

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cal information on problems of power plant engineering. Gives early history of the gas turbine, construction of the modern combustion turbine and compressor, thermodynamic considerations, and thermal efficiency and applications. Contains useful engineering data in text, chart, drawing and mathematical form. Well organized and extensively illustrated.

Heat Transfer. American Locomotive Co., Alco Products Div., 30 Church St., New York, N. Y.—Mean temperature difference calculator to aid in approximation of heat transfer surfaces when preparing estimates or specifications for heat exchanger equipment. Includes scales for the calculation of the logarithmic M.T.D. as well as correction factors for various shell passes, etc. Calculator is of sturdy cardboard construction. Price 25 cents.

Humidifiers. The Carrier Corp., Syracuse, N. Y.—Form 43G1—2-page sheet which illustrates and describes this concern's new industrial humidifier for use in textile mills, paper and printing plants and other industries. Also contains specifications, dimensions and cross-sectional drawings.

Hydrocarbons. Phillips Petroleum Co., Bartlesville, Okla.—Bulletin 96—64-page bulletin listing specifications, typical properties, shipping requirements, containers, and general uses of the hydrocarbons put out by this concern. Includes information on paraffins, cycloparaffins, olefins, diolefins, aromatics, petroleum ethers and naphthas. Also contains a table of physical constants of the various hydrocarbons. Illustrated. Contains a price schedule for commercial, pure and technical grades of hydrocarbons.

Leather Belt Conservation. E. F. Houghton & Co., 303 W. Lehigh Ave., Philadelphia, Pa.—Illustrated booklet entitled "How to Make Your Belts Last Longer" which summarizes in non-technical language information on leather belt conservation. Contains reference data and formulas, information on maintenance procedure, proper storage, etc.

Paper Products. Dennison Manufacturing Co., Framingham, Mass.—4-page folder describing briefly and illustrating various uses of paper products for war production contracts. Includes such uses as bomb and mine tags, detonator assembly trays, shell primer discs, powder bags, etc.

Pulp and Paper. Paper and Industrial Appliances, Inc., 122 E. 42nd St., New York, N. Y.—4-page folder entitled "Brammer Recording Consistency Control", for accurate control and recording of consistency regulation of pulps, paper stocks, viscose liquids, etc. Includes data on design, advantages, cross-sectional drawing of a representative installation and table of weights and volumes. Also 4-page folder entitled "Chemipulper" combining the Asplund defibrator and B-K reaction chamber for continuous production of semi-chemical pulp from wood, straw, bagasse and other cellulose materials. Contains illustrations, description of the process and data on applications in industry. Also 8-page folder dealing with the control charts put out by this concern for recording consistency control.

Pumps. Allis-Chalmers Manufacturing Co., Milwaukee, Wis.—Form B6018B—36-page publication giving complete and extensive engineering data on this concern's SS Unit pump and "Electrifugal". Contains head capacity tables, dimension charts, performance data and engineering recommendations, cross-sections and construction details, methods of figuring pumping heads, friction of water in pipes, and other similar engineering data. Extensively illustrated.

Pumps. Ingersoll-Rand, Cameron Pump Division, 11 Broadway, New York, N. Y.—Bulletin 7167—12-page folder illustrating and describing briefly the line of two-stage centrifugal pumps put out by this concern. Contains numerous photographs and cross-sectional views, performance tables, data on applications in chemical plants and various process industries, and a table showing friction of water in pipes.

Rubber Conservation. The B. F. Goodrich Co., Akron, Ohio—Bulletins 5 and 6 dealing with how to get the most service out of rubber hose and mats and matting, respectively. Contains practical suggestions in concise and easily understandable form. The number of copies desired for distribution among foremen and maintenance men should be stated.

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DISTILLED WATER

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OPERATION—The process is one of ion exchange using the Amberlite synthetic resins. In operation, water passes through two beds of special minerals, the first of which removes, by base exchange, the positive ions, such as calcium, magnesium, sodium, or iron, substituting hydrogen. The hydrogen combines with the negative sulphate, chloride, and nitrate ions to form the equivalent acids. (The carbonates form carbonic acid which passes on through as CO_2 and water, and the CO_2 can be very largely dispelled by aeration if its presence is undesirable.) This acidic water passes to a second tank where the negative ions (chlorides, sulphates, and nitrates) are removed by adsorption, giving a final effluent which compares very favorably with single distilled water.

1,000 gallons for less than a dollar!

Water produced by the Illco-Way method replaces distillation at *a fraction of the cost* . . . and meets the exacting standards of pharmaceutical houses, chemical plants, distilleries, mirror and battery manfacturers, porcelain enamelling plants and other industrial concerns requiring purified water.

Completely automatic (between periodic regenerations)—water is not evaporated, so no heat is required—pipes will not lime up—minimum maintenance cost. A unit delivering 300 gallons an hour occupies space about 4 x 10 feet. Made of finest material to protect purity of water. Available in units affording from 150 gallons an hour to 15,000 gallons an hour.

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Memphis, Tenn.

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International Water Supply, Ltd.	London, Ont.

WORLD'S LARGEST WATER DEVELOPERS

Safety Tools. Ampco Metal, Inc., 1745 S. 38th St., Milwaukee, Wis.—Folder which describes briefly the advantages and uses of this concern's line of safety tools for protection against fire and explosion. Illustrated.

Speed Control. Allis-Chalmers Mfg. Co., Milwaukee, Wis.—Bulletin B6013A—20-page booklet on this concern's "Vari-Pitch" speed changer. Gives numerous diagrams, operating data and selection tables. Contains extensive engineering data in chart form. Extensively illustrated.

Transformers. Westinghouse Electric & Mfg. Co., E. Pittsburgh, Pa.—Bulletin B3008—New bulletin which describes this concern's network transformers for oil refineries, ordnance works, and other industrial use. Includes a general discussion of systems on overhead, spot, vertical and industrial networks, transformers for each system, construction details, insulation against eddy currents, and accessories. Illustrations include a system diagram, close-up of transformer parts, sectional views and line drawings.

Testing. United States Testing Co., Inc., 1415 Park Ave., Hoboken, N. J.—106-page booklet entitled "Testing in Modern Industry." Describes briefly various types of testing in industry. Features conversion tables and specification standards for textiles, chemicals, metals and other materials. Describes briefly this concern's facilities for various testing jobs. Contains numerous and extensive tables on weights and measures, properties of yarns, relative humidity, classifications of raw silk, specific gravity and strength of various aqueous solutions, hardness conversion, and a list of reference books. Well illustrated.

Valves. Everlasting Valve Co., 49 Fisk St., Jersey City, N. J.—Bulletin E52B—4-page folder illustrating and describing briefly this concern's line of weight-operated valves with pendulum stop for protection against fire. Describes how the valves are designed for emergency shutoff or diversion of the flow of flammable liquids, or for diversion or concentration of water to sprinkler deluge or water curtain systems. Contains specifications and diagrammatic drawings.

Valves. The Edward Valve & Mfg. Co., Inc., East Chicago, Ind.—Catalog 12C—54-page catalog section on this concern's cast steel valves of globe, angle, check, and feed-line types. Describes and illustrates each unit with photographs and cross-sectional drawings and gives dimensions and weights in table form. Also contains engineering data on flange facings, pressure-temperature tables, and helpful hints on valve usage. Also an index of the concern's catalog sections.

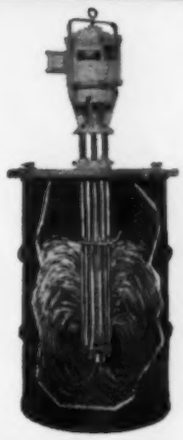
Vibrating Screens. Allis-Chalmers Mfg. Co., Milwaukee, Wis.—Bulletin B1651A—16-page bulletin which describes this concern's new "Ripl-Flo" vibrating screen operating on the principle of "perfect-circle" vibration. Describes advantages, operating principles, applications and includes specification tables and diagrammatic sketches. Illustrated.

Waterproofing. American Colloid Co., 363 W. Superior St., Chicago, Ill.—Data Sheet 231L—4-page folder which describes briefly service performance of this concern's "Volclay" bentonite base material for waterproofing jobs. Includes data on the use of this bentonite material in earthworks, for sealing cracks and joints in concrete, wood and other materials, and the swellability of clays in foundations.

Water Testing. The Bird-Archer Co., 400 Madison Ave., New York, N. Y.—20-page illustrated booklet containing concise but complete information on water testing equipment put out by this concern, methods of making all control tests, conductivity apparatus, proportioning pumps, and chemical feeders. Gives detailed information on the why and how of water analyses. Contains list prices on each item. Illustrated.

Wrought Iron Products. A. M. Byers Co., Pittsburgh, Pa.—1942 general catalog of this concern's wrought iron products and welded steel pipe and tubular products, standard alloys and high heat resisting alloy steels. Contains extensive tables on dimensions and specifications, tolerances, and similar data.

S-T-R-E-T-C-H Man Hours



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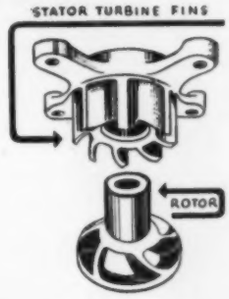

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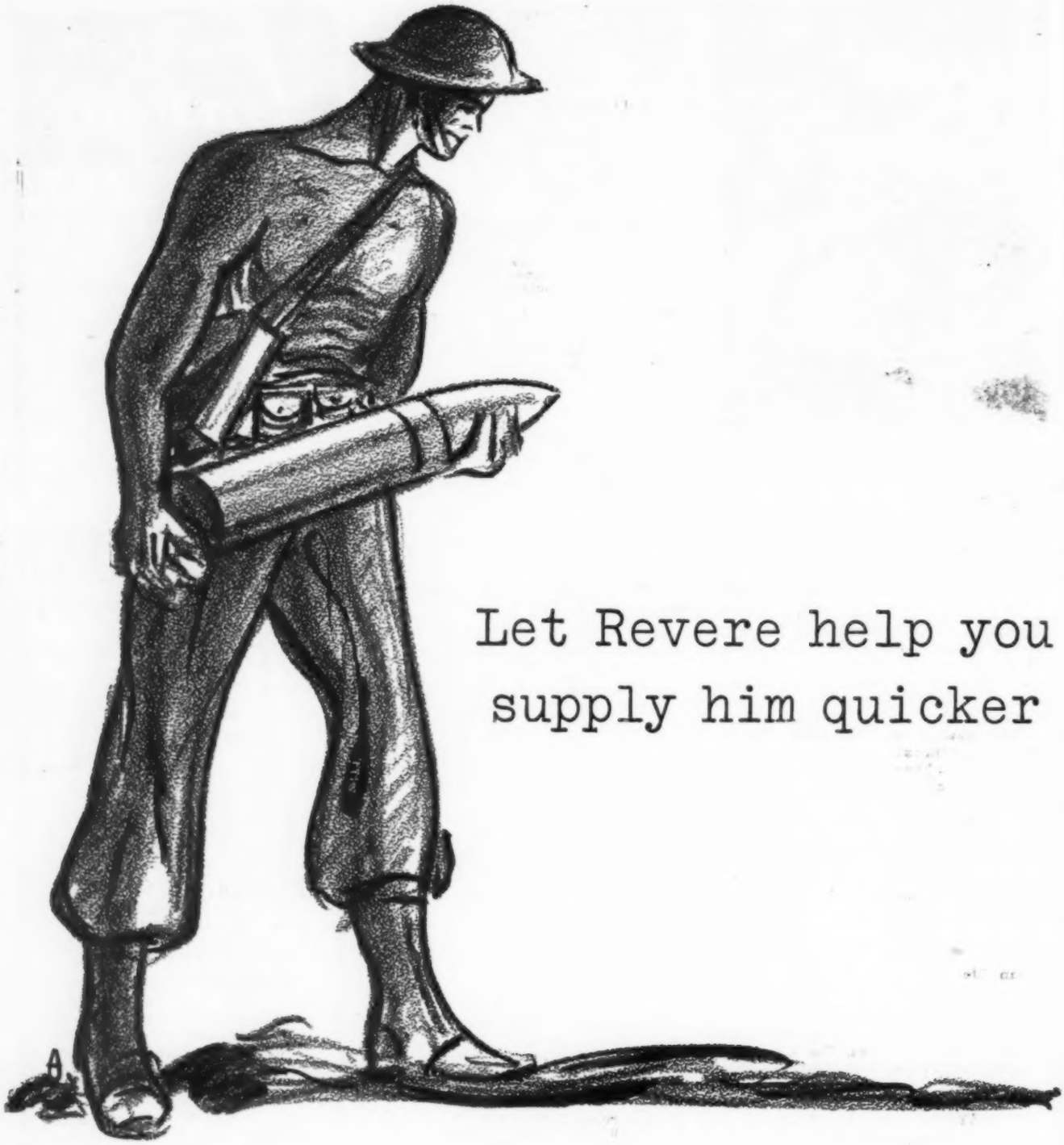

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PRODUCTION AND CONSUMPTION OF CHEMICALS CONTINUE ON STEADILY EXPANDING SCALE

CHEM & MET ECONOMICS & MARKETS

ACCORDING to the indexes of the Federal Reserve Board, production of chemicals for the first quarter of this year was close to 28 percent above that for the corresponding period of last year. The *Chem. & Met.* index for industrial consumption shows a gain of about 12 percent for the same periods. While it may be a misnomer to refer to the output of some industries as an indication of industrial consumption of chemicals since a good part of the finished products of many plants is used somewhere in the war program,

Chem. & Met. Index for Industrial Consumption of Chemicals

(1935—100)

	Feb.	March
Fertilizer	35.72	37.58
Pulp and paper	21.30	23.35
Petroleum refining	13.19	14.51
Glass	15.18	16.65
Paint and varnish	14.67	15.61
Iron and steel	12.05	13.52
Rayon	13.33	15.24
Textiles	11.35	12.20
Coal products	8.74	9.80
Leather	5.02	5.10
Industrial explosives	5.49	5.22
Rubber	3.00	3.00
Plastics	3.80	4.60
	162.84	176.38

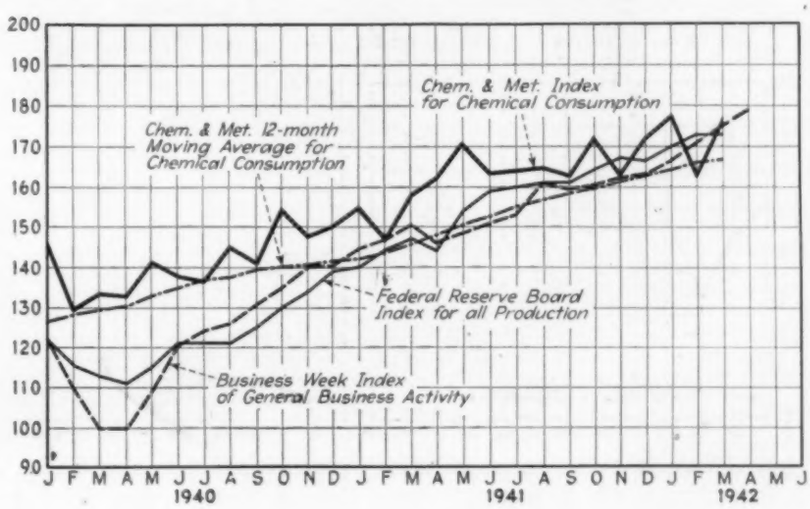
it is important to note that the conversion of plants from civilian to war purposes has had but little effect in the way of curtailing those industries which ordinarily are the largest consumers of chemicals.

Last month the War Production Board instructed cotton mills to convert specified percentages of their looms now producing a long list of cotton fabrics to the production of bag osnaburg and bag sheetings. While a part of the looms to be converted represent branches of the industry where the use of chemicals was relatively light, there is no doubt that the effects of the order will be to reduce the amount of chemicals used in the textile plants. With the exception of pulp mills, where bleaching operations have been curtailed, other so-called industrial industries have been able to substitute for chemicals which are in small supply and the overall result has been to increase chemical consumption. The rubber industry has, of course, been adversely affected by the limitations placed on rubber distribution and there are no data available for the amounts of crude which are now being used and the index number given for that industry is without any authority.

The index for chemical consumption for March is 176.38 compared with a revised figure of 162.84 for February. Last year the indexes for March and February were 158.28 and 146.81 respectively. Season influences are working in favor of lower operations in the fertilizer trade. Petroleum refining, although maintained at a relatively high rate has dropped considerably from the peak and this condition may be expected to continue until distribution facilities have been increased. Glass plants are active in all departments with the exception of the plate glass branch. Sales of paint and varnish were unusually high during the first quarter with the bulk of deliveries reported on account of war work. Steel production has been stepped up in recent weeks with new records for output. While some branches of rayon yarn manufacture have not been working at capacity, the total output has bettered last years totals and staple production has run considerably above last year's figures. The situation in the field of plastics is somewhat complicated as some types are reported to have fallen in output but other types have been produced in larger quantities and this is especially true for cellulose acetate molding composition.

In some cases, production of sulphuric acid has been curtailed due to the fact that stocks of sulphur on hand have been well depleted. Consumers of sulphur were urged last month to build up reserves as a protection against possible difficulties which might arise from interference with transport facilities. One of the large producers states that the sulphur industry finds itself well able to cooperate with users. All production and shipments records were broken last year and in the first quarter of this year output was about 20 percent higher than in the first quarter of 1941.

Production and consumption of industrial alcohol have risen steadily and in each case will be about twice in volume what it was last year if present calculations are borne out. Apparently the required total will be forthcoming as available plant capacities with the help of distilleries are estimated to be sufficient for the estimated requirements. Data for alcohol production will be withheld for the duration.

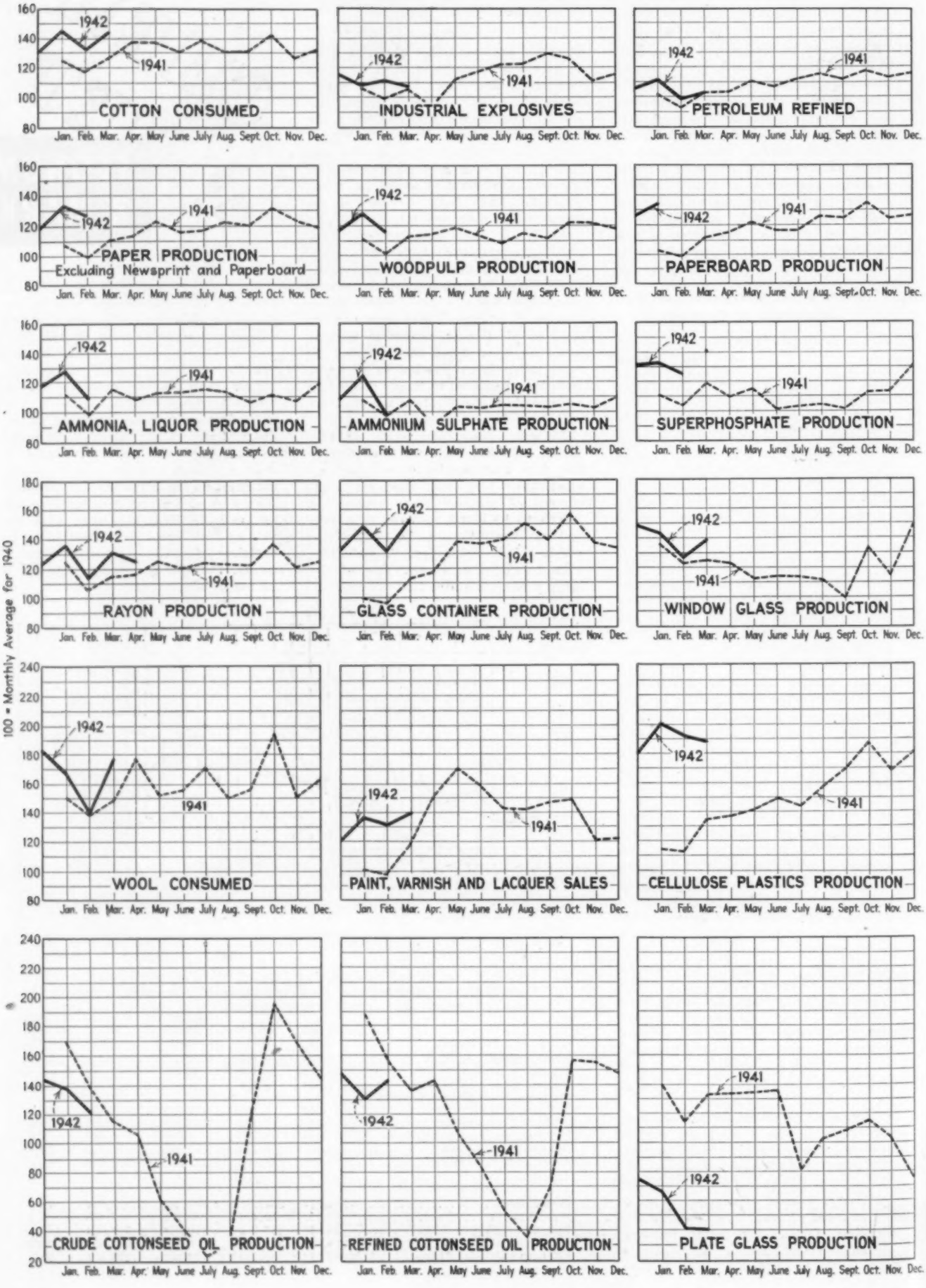


Production and Consumption Data for Chemical-Consuming Industries

	March 1940	March 1941	January-March 1942	January-March 1941	Per cent of gain for 1942
Production					
Glass containers, 1,000 gr	6,935	5,128	19,655	14,013	40.3
Plate glass, 1,000 sq. ft	5,565	18,266	20,308	53,280	61.9*
Window glass, 1,000 boxes	1,583	1,417	4,678	4,375	6.9
Cellulose acetate plastics, 1,000 lb.					
Sheets, rods and tubes	519	465	1,671	1,425	17.3
Molding composition	3,644	2,232	10,910	5,742	90.0
Nitrocellulose plastics, 1,000 lb	1,434	1,308	4,428	3,606	22.8
Pyroxylin spread, 1,000 lb	5,252	6,759	17,092	19,015	10.1*
Rayon yarn, 1,000 lb	40,300	35,600	117,100	102,000	14.8
Consumption					
Cotton, bales	966,631	854,767	2,806,285	2,493,034	12.6
Wool, 1,000 lb	60,137	50,424	158,053	148,448	6.5
Industrial explosives, 1,000 lb	36,453	35,722	110,854	105,433	5.1
Cottonseed oil, bbl	225,288	317,622	757,104	985,866	23.2*
Paint, varnish sales, $1,000	48,070	40,185	140,290	108,481	29.3

* Percent of decrease.

Production and Consumption Trends



● For posting on bulletin boards and shop walls in Linde customers' plants, a two-color version of the poster shown above is available. These posters will remind your employees of the vital need for fullest utilization of existing stocks of oxygen and acetylene cylinders and will thus help assure your gas supply. Ask any Linde office for the quantity you require, specifying Form 5104.

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Unit of Union Carbide and Carbon Corporation

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Peerless engineering, research and design give you the most modern improvements in higher sustained efficiencies, widest range of capacities, trouble-free performance and lower operating and maintenance costs.

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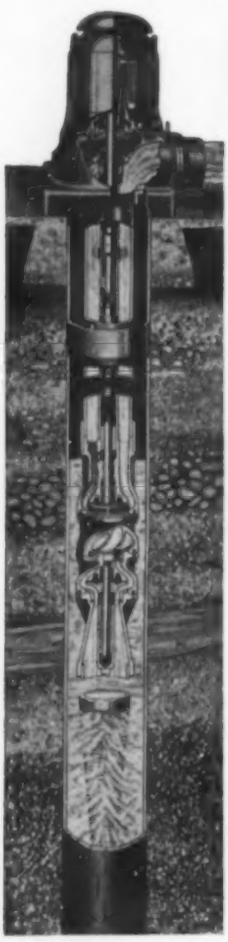

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WATER OR OIL LUBRICATION
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TURBINE PUMPS

EARLIER PRICE CEILINGS AND AGREEMENTS DISCOUNT EFFECT OF NEW GENERAL PRICE ORDER

From a distribution standpoint, the most important factors in the market are the controls which are exercised by government authorities. Restrictions on industry outputs and on use of materials are steadily growing in number. Recently, natural resins which had been substituted in many cases where synthetic resins formerly were used, have become scarce and in order to conserve supplies, an order was issued prohibiting their use in barn paint, farm equipment finishes, floor finishes, freight car paints, interior house paints, pencil finishes, playing card finishes, porch and deck paints, road marking paints, spirit label varnishes, and toy and novelty finishes. Manufacturers of rotogravure inks may use 75 percent of the amount used in the corresponding quarter of last year. For other uses processors are restricted to 50 percent of their 1941 amounts. Among the exceptions to the order is the use of natural resins in chemical plants where corrosive action makes use of any other material impractical.

Beverage alcohol from 100 to 189 proof has been placed under complete allocation control in order to increase the industrial alcohol supply. The order requires distillers to deliver specified quantities to rectifying plants. Use of high wines to make industrial alcohol had been carried on voluntarily by 25 distilleries and this order extended that program throughout the industry.

All rubber substitutes of the type of Koroseal and vinylite also came under allocations. Originally the order included only polymerized vinyl chloride and its co-polymer with vinyl acetate. The new order brings under the restriction all co-polymers of polyvinyl chloride and all co-polymers and polymers of vinyl chloride.

A change in computing permissible use of chlorine in pulp manufacture has been made whereby the limitation is based on the amount used per ton of rag stock treated instead of on total amount consumed in a base period.

Use of tung and oiticica oils, either alone or in mixtures with other oils is restricted to war orders with a rating of A-2 or higher, to orders placed by the Defense Supplies Corp., to orders for manufacture of linings or coatings for cans used in food processing, and to orders to comply with safety, underwriter or sanitary regulations.

To conserve substantial quantities of critical materials, production of storage batteries for passenger automobiles and light trucks has been prohibited except in specified minimum ampere hour capacities, production from April through September to be limited to 75 percent of the number sold by each manufacturer during the corresponding quarter last year, and rigid restrictions are placed on inventories. Savings under the program are estimated at 23,000 tons of lead, 800 tons of antimony and a considerable amount of rubber. Last year about 16,000,000 batteries were sold for replacement purposes.

The order of April 25, which directed the taking over of the entire stock and production of heavy weight sole leather for military and lend-lease requirements, probably will have no effect on the use of tanning materials as it does not indicate any reduction in the amount of leather to be turned out.

Chemical equipment likewise has come under complete allocation control in the case of heavy compressors. War requirements for heavy compressors have put a strain on existing supplies. The synthetic rubber, toluol, aviation gas, aviation lubricating oil, and oxygen and ammonia programs require large amounts of compressors and also more are needed in tank, plane, aluminum and steel plants.

The A-10 ratings for use of chlorinated hydrocarbon solvents has been extended to include fumigation of stored products, fire extinguishers, laboratories, hospitals and public institutions, processing and manufacturing foods, chemicals, rubber, petroleum and plywood, cleaning metal parts of electrical equipment, refrigerants, and degreasing machines making war materials.

The general maximum price regulation which was announced on April 28 and which places ceilings at the highest levels at which the individual producer sold during March was not so sweeping in the case of chemicals as for some of commodity markets. Most of the large tonnage chemicals either had previously been placed under ceilings or maximum prices had been arranged through agreements. The extension of the price control to export shipments, however may be expected to stabilize values in the spot market where much export business has been placed in the last year or more at prices

CHEM. & MET. Weight Index of CHEMICAL PRICES

Base=100 for 1937

This month	**109.40**
Last month	109.54
May, 1941	100.35
May, 1940	98.71

Control over prices is so general that only minor changes are to be expected unless ceiling levels for some of the materials may be given individual attention. Turpentine is among the products which have an open market and values have fallen steadily in recent weeks.

which at times were not in line with sales made by first hands. The order became effective on April 30. The export price for a producer is defined as his maximum domestic price for the specified material to which may be added an amount not in excess of the average premium charged in the export trade for the particular services or functions performed during either in the July-December, 1940 or March 15-April 15, 1941 periods, whichever is lower. Additional costs to be absorbed by the exporter such as war risk insurance, consular fees, demurrage charges, and shipping charges also may be added in arriving at an export price.

Theoretically the placing of a ceiling over all chemicals should result in an absolute stability of prices but this point has not yet been reached as some of the chemical products are selling below the highest March levels as may be cited in the case of turpentine. There also is some speculation regarding the position of some individual producers since highest prices obtained in March for a few chemicals were not the same in the case of all producers and if the March maximums are to prevail, there still will be a range in prices according to seller.

In connection with the establishment of price ceilings it is interesting to note that the Harshaw Chemical Co. was authorized to sell about 45 tons of dynamite glycerine to the Treasury Procurement Division at a price exceeding the maximum set Price Schedule 38. This glycerine was refined from crude purchased in South America prior to the existence of the price control. The company offered to transfer the glycerine to the war effort without profit and the offer was accepted.

While the general price order is generally effective, it is superseded in some instances by particular regulations. In this category is fluorspar for which after May 11, the highest price shall be that which was in effect last Jan. 2 f.o.b. railroad or waterway from which such producer customarily ships from mine or mill. A separate regulation for prices on mixed fertilizers, superphosphate and potash was issued because its provisions for sales of 250 lb. or more are especially designed for that trade.

CHEM. & MET.

Weighted Index of Prices for

OILS & FATS

Base=100 for 1937

This month	**143.93**
Last month	143.89
May, 1941	108.79
May, 1940	78.88

While many of the oils and fats are being held at maximum prices, the flaxseed market has been easier and some slowing up in demand for linseed oils brought out offerings at lower levels but later the market firmed with a rising price trend.

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THE *Cooper* ALLOY FOUNDRY CO.
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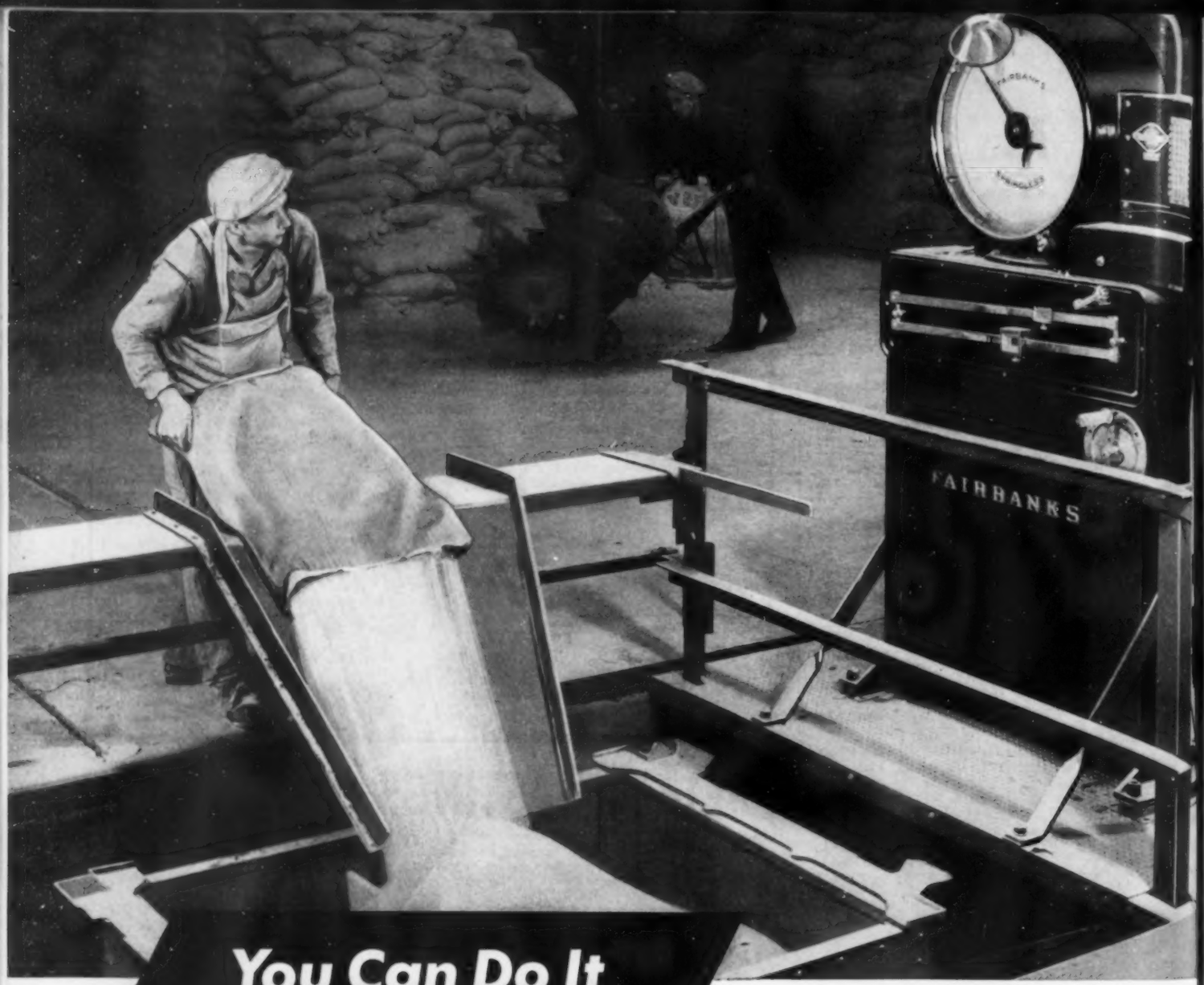

To speed compounding of materials, this Fairbanks Dial Scale was built into a charging car which travels in a pit. At the touch of a button the Printomatic gives an accurate printed record of each batch.

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● Rare is the weighing job which can't be done faster and more precisely with today's vastly improved scales. These scales *print* weight records more quickly than a man can read and write them. They *eliminate human errors.* They weigh while materials are *on the move.*

But—important as those advantages are—don't dismiss modern scales as nothing more than better weighing instruments. For scales have assumed amazing *extra* functions which often speed production surprisingly. They *count* small parts and products. They furnish weight records for accounting and inventory control. They weigh and disburse preset amounts *automatically,* and can keep ingredient proportions *secret!*

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We are anxious to do everything we can to help speed American production. Possibly our scale engineers could suggest new and more efficient applications of scales in *your* plant, or modifications of your present scales to attune them to today's tempo. Write Fairbanks, Morse & Co., Dept. E19, 600 S. Michigan Ave., Chicago. Branches and service stations throughout the United States and Canada.

FAIRBANKS · MORSE FAIRBANKS SCALES **SCALES**

DIESEL ENGINES ELECTRICAL MACHINERY MAGNETOS RAILROAD EQUIPMENT WASHERS-IRONERS STOKERS
PUMPS MOTORS FAIRBANKS SCALES WATER SYSTEMS FARM EQUIPMENT AIR CONDITIONERS

CHEM & MET

CURRENT PRICES

INDUSTRIAL CHEMICALS

	Current Price	Last Month	Last Year
Acetone, drums, lb	$0.168–$0.173	$0.168– $.173	$0.07½–$0.08
Acid, acetic, 28%, bbl., cwt	3.38 – 3.63	3.38 – 3.63	2.23 – 2.48
Glacial 99.5%, drums	9.15 – 9.40	9.15 – 9.40	8.43 – 8.68
U. S. P. X 1, 99.5%, dr	10.95 –11.20	10.95 –11.20	10.25 –10.50
Boric, bbl., ton	108.00–113.00	108.00–113.00	106.00–111.00
Citric, kegs, lb	.20 – .23	.20 – .23	.20 – .23
Formic, cbys., lb	.10½– .11	.10½– .11	.10½– .11
Gallic, tech., bbl., lb	1.10 – 1.15	1.10 – 1.15	.90 – 1.00
Hydrofluoric 30% drums, lb	.08 – .08½	.08 – .08½	.08 – .08½
Lactic, 44%, tech., light, bbl., lb	.073– .075	.073– .075	.06½– .06¾
Muriatic, 18°, tanks, cwt	1.05 –.....	1.05 –.....	1.05 –.....
Nitric, 36°, carboys, lb	.05 – .05½	.05 – .05½	.05 – .05½
Oleum, tanks, wks., ton	18.50 –20.00	18.50 –.....	18.50 –20.00
Oxalic, crystals, bbl., lb	.11½– .13	.11½– .13	.10½– .12
Phosphoric, tech., c'bys., lb	.07½– .08½	.07½– .08½	.07½– .08½
Sulphuric, 60°, tanks, ton	13.00 –.....	13.00 –.....	13.00 –.....
Sulphuric, 66°, tanks, ton	16.50 –.....	16.50 –.....	16.50 –.....
Tannic, tech., bbl., lb	.71 – .73	.71 – .73	.54 – .56
Tartaric, powd., bbl., lb	.70 –.....	.70 –.....	.63 –.....
Tungstic, bbl., lb	nom.....	nom.....	nom.....
Alcohol, amyl	.....	.....	.....
From Pentane, tanks, lb	.131–.....	.131–.....	.111–.....
Alcohol, Butyl, tanks, lb	.158–.....	.158–.....	.09 –.....
Alcohol, Ethyl, 190 p'f., bbl., gal	8.19 – 8.25	8.19 – 8.25	6.04 –.....
Denatured, 190 proof	.....	.....	.....
No. 1 special, dr., gal. wks	.60 –.....	.60 –.....	.33 –.....
Alum, ammonia, lump, bbl., lb	.03½– .04	.03½– .04	.03½– .04
Potash, lump, bbl., lb	.04 – .04½	.04 – .04½	.03½– .04
Aluminum sulphate, com. bags, cwt	1.15 – 1.40	1.15 – 1.40	1.15 – 1.40
Iron free, bg., cwt	1.85 – 2.10	1.85 – 2.10	1.60 – 1.70
Aqua ammonia, 26°, drums, lb	.02½– .03	.02½– .03	.02½– .03
tanks, lb	.02 – .02¾	.02 – .02¾	.02 – .02¾
Ammonia, anhydrous, cyl., lb	.16 –.....	.16 –.....	.16 –.....
tanks, lb	.04½–.....	.04½–.....	.04½–.....
Ammonium carbonate, powd. tech., casks, lb	.09½– .12	.09½– .12	.09 – .12
Sulphate, wks., cwt	1.45 –.....	1.45 –.....	1.45 –.....
Amylacetate tech., from pentane, tanks, lb	.145–.....	.145–.....	.105–.....
Antimony Oxide, bbl., lb	.15 –.....	.15 –.....	.12 –.....
Arsenic, white, powd., bbl., lb	.04 – .04½	.04 – .04½	.03½– .04
Red, powd., kegs, lb	nom.....	nom.....	nom.....
Barium carbonate, bbl., ton	60.00 –65.00	60.00 –65.00	52.50 –57.50
Chloride, bbl., ton	79.00 –81.00	79.00 –81.00	79.00 –81.00
Nitrate, casks, lb	.11 – .12	.10½– .11	.09½– .10
Blanc fix, dry, bbl., lb	.03½– .04	.03½– .04	.03½– .04
Bleaching powder, f.o.b., wks., drums, cwt	2.25 – 2.35	2.25 – 2.35	2.00 – 2.10
Borax, gran., bags, ton	44.00 –.....	44.00 –.....	43.00 –.....
Bromine, cs., lb	.30 – .32	.30 – .32	.30 – .32
Calcium acetate, bags	3.00 –.....	3.00 –.....	1.90 –.....
Arsenate, dr., lb	.07 – .08	.07 – .08	.06½– .06¾
Carbide drums, lb	.04½– .05	.04½– .05	.04½– .05
Chloride, fused, dr., del., ton	18.00 –24.00	18.00 –24.00	19.00 –24.50
flake, bags, del., ton	18.50 –25.00	18.50 –25.00	18.50 –25.00
Phosphate, bbl., lb	.07½– .08	.07½– .08	.07½– .08
Carbon bisulphide, drums, lb	.05½–.....	.05½–.....	.05 –.....
Tetrachloride drums, gal	.73 – .80	.73 – .80	.66½– .73
Chlorine, liquid, tanks, wks., lb	2.00 –.....	2.00 –.....	1.75 –.....
Cylinders	.05½– .06	.05½– .06	.05½– .06
Cobalt oxide, cans, lb	1.84 – 1.87	1.84 – 1.87	1.84 – 1.87
Copperas, bgs., f.o.b., wks., ton	18.00 –19.00	18.00 –19.00	18.00 –19.00
Copper carbonate, bbl., lb	.18 – .20	.18 – .20	.10 – .16
Sulphate, bbl., cwt	5.15 – 5.40	5.15 – 5.40	4.75 – 5.00
Cream of tartar, bbl., lb	.57 –.....	.57 –.....	.52 –.....
Diethylene glycol, dr., lb	.14 – .15½	.14 – .15½	.22 – .23
Epsom salt, dom., tech., bbl., cwt	1.90 – 2.00	1.90 – 2.00	1.80 – 2.00
Ethyl acetate, drums, lb	.12–.....	.12 –.....	.07½–.....
Formaldehyde, 40%, bbl., lb	.05½– .06	.05½– .06½	.05½– .06
Furfural, tanks, lb	.09 –.....	.09 –.....	.09 –.....
Fusel oil, drums, lb	.18 – .19	.18 – .19	.16 – .17
Glaubers salt, bags, cwt	1.05 – 1.10	1.05 – 1.10	.95 – 1.00
Glycerine, c.p., drums, extra, lb	.18½–.....	.18½–.....	.12½–.....
Lead:			
White, basic carbonate, dry casks, lb	.08½–.....	.08½–.....	.07½–.....
White, basic sulphate, sck., lb	.07½–.....	.07½–.....	.07½–.....
Red, dry, sck., lb	.09½– .09¾	.09½–	.0835–.....
Lead acetate, white crys., bbl., lb	.12½– .13	.12½– .13	.11 – .12
Lead arsenate, powd., bag, lb	.11 – .12	.11 – .12	.09½– .11
Lime, chem., bulk, ton	8.50 –.....	8.50 –.....	8.50 –.....
Litharge, pwd., csk., lb	.08½–.....	.08½–.....	.0735–.....
Lithopone, bags, lb	.04½– .04½	.04½– .04½	.038– .04
Magnesium carb., tech., bags, lb	.06½– .06½	.06½– .06½	.06½– .06½

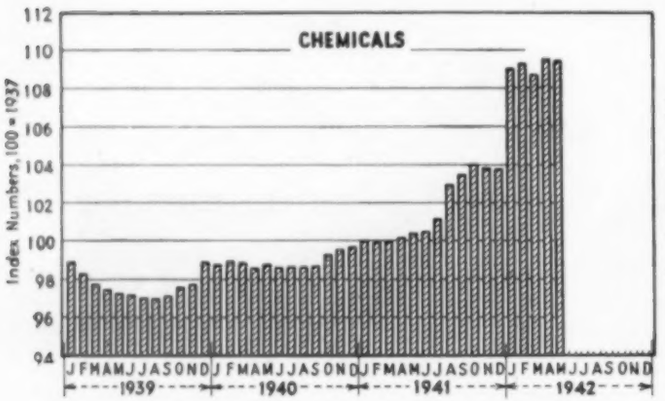
The accompanying prices refer to round lots in the New York market. Where it is the trade custom to sell f.o.b. works, quotations are given on that basis and are so designated. Prices are corrected to May 13

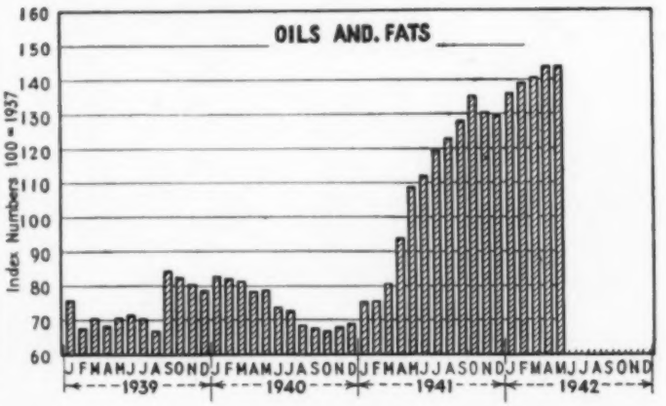
	Current Price	Last Month	Last Year
Methanol, 95%, tanks, gal	.60 –.....	.60 –.....	.29 –.....
97%, tanks, gal	.60 –.....	.60 –.....	.30 –.....
Synthetic, tanks, gal	.28 –.....	.28 –.....	.30 –.....
Nickel salt, double, bbl., lb	.13½– .13¾	.13½– .13¾	.13½–.....
Orange mineral, csk., lb	.12½–.....	.12½–.....	.11½–.....
Phosphorus, red, cases, lb	.40 – .42	.40 – .42	.40 – .42
Yellow, cases, lb	.18 – .25	.18 – .25	.18 – .25
Potassium bichromate, casks, lb	.09½– .10	.09½– .10	.08½– .09
Carbonate, 80–85%, calc. csk., lb	.06½– .07	.06½– .07	.06½– .07
Chlorate, powd., lb	.10 – .12	.10 – .12	.10 – .12
Hydroxide (c'stic potash) dr., lb	.07 – .07½	.07 – .07½	.07 – .07½
Muriate, 60% bags, unit	.53½–.....	.53½–.....	.53½–.....
Nitrate, bbl., lb	.05½– .06	.05½– .06	.05½– .06
Permanganate, drums, lb	.19½– .20	.19½– .20	.19½– .20
Prussiate, yellow, casks, lb	.17 – .18	.17 – .18	.15 – .16
Sal ammoniac, white, casks, lb	.0515– .06	.0515– .06	.0515– .06
Salsoda, bbl., cwt	1.00 – 1.05	1.00 – 1.05	1.00 – 1.05
Salt cake, bulk, ton	17.00 –.....	17.00 –.....	17.00 –.....
Soda ash, light, 58%, bags, contract, cwt	1.05 –.....	1.05 –.....	1.05 –.....
Dense, bags, cwt	1.10 –.....	1.10 –.....	1.10 –.....
Soda, caustic, 76%, solid, drums, cwt	2.30 – 3.00	2.30 – 3.00	2.30 – 3.00
Acetate, del., bbl., lb	.05 – .06	.04½– .06	.04 – .05
Bicarbonate, bbl., cwt	1.70 – 2.00	1.70 – 2.00	1.70 – 2.00
Bichromate, casks, lb	.07½– .08	.07½– .08	.06½– .07
Bisulphate, bulk, ton	16.00 –17.00	16.00 –17.00	16.00 –17.00
Bisulphite, bbl., lb	.03 – .04	.03 – .04	.03 – .04
Chlorate, kegs, lb	.06½– .06¾	.06½– .06¾	.06½– .06¾
Cyanide, cases, dom., lb	.14 – .15	.14 – .15	.14 – .15
Fluoride, bbl., lb	.08 – .09	.08 – .09	.07 – .08
Hyposulphite, bbl., cwt	2.40 – 2.50	2.40 – 2.50	2.40 – 2.50
Metasilicate, bbl., cwt	2.50 – 2.65	2.50 – 2.65	2.35 – 2.40
Nitrate, bulk, cwt	1.35 –.....	1.35 –.....	1.45 –.....
Nitrite, casks, lb	.06½– .07	.06½– .07	.06½– .07
Phosphate, tribasic, bags, lb	2.70 –.....	2.70 –.....	2.35 –.....
Prussiate, yel. drums, lb	.10½– .11	.10½– .11	.10½– .11
Silicate (40° dr.), wks., cwt	.80 – .85	.80 – .85	.80 – .85
Sulphide, fused, 60–62%, dr. lb	.03 – .03½	.03 – .03½	.02½– .03
Sulphite, crys., bbl., lb	.02½– .02¾	.02½– .02½	.02½– .02¾
Sulphur, crude at mine, bulk, ton	16.00 –.....	16.00 –.....	16.00 –.....
Chloride, dr., lb	.03 – .04	.03 – .04	.03 – .04
Dioxide, cyl., lb	.07 – .08	.07 – .08	.07 – .07½
Flour, bag, cwt	1.90 – 2.40	1.90 – 2.40	1.60 – 3.00
Tin Oxide, bbl., lb	.55 –.....	.55 –.....	.54 –.....
Crystals, bbl., lb	.39½–.....	.39½–.....	.39 –.....
Zinc, chloride, gran., bbl., lb	.05½– .06	.05 – .06	.05 – .06
Carbonate, bbl., lb	.14 – .15	.14 – .15	.14 – .15
Cyanide, dr., lb	.33 – .35	.33 – .35	.33 – .35
Dust, bbl., lb	.10½–.....	.09½–.....	.09½–.....
Zinc oxide, lead free, bag, lb	.07½–.....	.07½–.....	.06½–.....
5% leaded, bags, lb	.07¾–.....	.07½–.....	.06½–.....
Sulphate, bbl., cwt	3.85 – 4.00	3.85 – 4.00	3.15 – 3.25

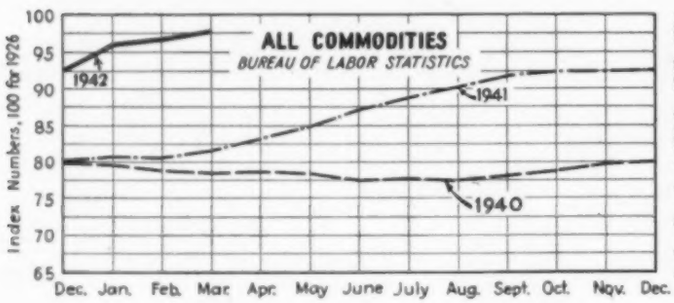
OILS AND FATS

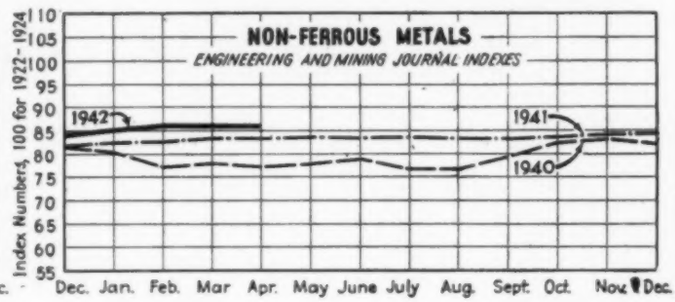
	Current Price	Last Month	Last Year
Castor oil, 3 bbl., lb	$0.13½–$0.14½	$0.13½–$0.14½	$0.11 –$0.11½
Chinawood oil, bbl., lb	.38 –.....	.38 –.....	.31 –.....
Coconut oil, Ceylon, tank, N. Y., lb	nom	nom	.07 –.....
Corn oil crude, tanks (f.o.b. mill), lb	.12½–.....	.12½–.....	.09½–.....
Cottonseed oil, crude (f.o.b. mill), tanks, lb	.12½–.....	.12½–.....	.09½–.....
Linseed oil, raw car lots, bbl., lb	.141–.....	.141–.....	.109–.....
Palm, casks, lb	.09 –.....	.09 –.....	.05½–.....
Peanut oil, crude, tanks (mill), lb	.13 –.....	.13 –.....	.09½–.....
Rapeseed oil, refined, bbl., lb	nom	nom	.12 –.....
Soya bean, tank, lb	.11½–.....	.11½–.....	.08½–.....
Sulphur (olive foots), bbl., lb	.19½–.....	.19 –.....	.14½–.....
Cod, Newfoundland, bbl., gal	nom	nom	nom .....
Menhaden, light pressed, bbl., lb	.114–.....	.114–.....	.10 –.....
Crude, tanks (f.o.b. factory) gal	.66 –.....	.66 –.....	.50 –.....
Grease, yellow, loose, lb	.09295–.....	.09295–.....	.06½–.....
Oleo stearine, lb	.09½–.....	.09½–.....	.09½–.....
Oleo oil, No. 1	.11½–.....	.11½–.....	.10½–.....
Red oil, distilled, dp.p. bbl., lb	.12 –.....	.12 –.....	.10½–.....
Tallow extra, loose, lb	.097125–.....	.097125–.....	.07½–.....

Chem. & Met.'s Weighted Price Indexes








NON-FERROUS METALS
ENGINEERING AND MINING JOURNAL INDEXES
Index Numbers, 100 for 1922-1924
1942
1941
1940
Dec. Jan. Feb. Mar. Apr. May June July Aug. Sept. Oct. Nov. Dec.

Coal-Tar Products

	Current Price	Last Month	Last Year
Alpha-napthol, crude bbl., lb.	$0.52 -$0.55	$0.52 -$0.55	$0.52 -$0.55
Alpha-naphthylamine, bbl., lb.	.32 - .34	.32 - .34	.32 - .34
Aniline oil, drums, extra, lb.	.15 - .16	.15 - .16	.15 - .16
Aniline, salts, bbl., lb.	.22 - .24	.22 - .24	.22 - .24
Benzaldehyde, U.S.P., dr., lb.	.85 - .95	.85 - .95	.85 - .95
Benzidine base, bbl., lb.	.70 - .75	.70 - .75	.70 - .75
Benzoic acid, U.S.P., kgs., lb.	.54 - .56	.54 - .56	.54 - .56
Benzyl chloride, tech., dr., lb.	.23 - .25	.23 - .25	.23 - .25
Benzol, 90%, tanks, works, gal.	.15 -.....	.15 -.....	.14 -.....
Beta-naphthol, tech., drums, lb.	.23 - .24	.23 - .24	.23 - .24
Cresol, U.S.P., dr., lb.	.11 -.....	.11 - .11	.09½ - .10
Cresylic acid, dr., wks., gal.	.81 - .83	.81 - .83	.58 - .60
Diethylaniline, dr., lb.	.40 - .45	.40 - .45	.40 - .45
Dinitrophenol, bbl., lb.	.23 - .25	.23 - .25	.23 - .25
Dinitrotoluol, bbl., lb.	.18 - .19	.18 - .19	.15½ - .16
Dip oil, 15%, dr., gal.	.23 - .25	.23 - .25	.23 - .25
Diphenylamine, dr. f.o.b. wks., lb.	.60 -.....	.60 -.....	.....
H-acid, bbl., lb.	.45 - .50	.45 - .55	.45 - .50
Naphthalene, flake, bbl., lb.	.07 - .07½	.07 - .07½	.07 - .07½
Nitrobenzene, dr., lb.	.08 - .09	.08 - .09	.08 - .09
Para-nitraniline, bbl., lb.	.47 - .49	.47 - .49	.47 - .49
Phenol, U.S.P., drums, lb.	.13 -.....	.13 -.....	.12 -.....
Picric acid, bbl., lb.	.35 - .40	.35 - .40	.35 - .40
Pyridine, dr., gal.	1.70 - 1.80	1.70 - 1.80	1.70 - 1.80
Resorcinol, tech., kegs, lb.	.75 - .80	.75 - .80	.75 - .80
Salicylic acid, tech., bbl., lb.	.33 - .40	.33 - .40	.33 - .40
Solvent naptha, w.w., tanks, gal.	.27 -.....	.27 -.....	.27 -.....
Toluidine, bbl., lb.	.86 - .88	.86 - .88	.86 - .88
Toluol, drums, works, gal.	.33 -.....	.33 -.....	.30 -.....
Xylol, com, tanks, gal.	.26 -.....	.26 -.....	.26 -.....

Miscellaneous

	Current Price	Last Month	Last Year
Barytes, grd., white, bbl., ton.	$22.00–$25.00	$22.00–$25.00	$22.00–$25.00
Casein, tech, bbl., lb.	.20 - .25	.19½ - .25	.16 - .17
China clay, dom., f.o.b. mine, ton.	8.00 -20.00	8.00 -20.00	8.00 -20.00
Dry colors			
Carbon gas, black (wks.), lb.	.0335- .30	.0335- .30	.028- .30
Prussian blue, bbl., lb.	.36 - .37	.36 - .37	.36 - .37
Ultramarine blue, bbl., lb.	.11 - .26	.11 - .26	.10 - .26
Chrome green, bbl., lb.	.21½ - .30	.21½ - .30	.21 - .27
Carmine, red, tins, lb.	4.60 - 4.75	4.60 - 4.75	4.85 - 5.00
Para toner, lb.	.75 - .80	.75 - .80	.75 - .80
Vermilion, English, bbl., lb.	3.05 - 3.10	3.05 - 3.10	3.12 - 3.20
Chrome yellow, C.P., bbl., lb.	.14½ - .15½	.14½ - .15½	.14½ - .15½
Feldspar, No. 1 (f.o.b.N.C.), ton.	6.50 - 7.50	6.50 - 7.50	6.50 - 7.50
Graphite, Ceylon, lump, bbl., lb.	.08 - .10	.08 - .10	.06 - .06½
Gum copal Congo, bags, lb.	.09 - .30	.09 - .30	.06 - .30
Manila, bags, lb.	.09 - .15	.09 - .14	.09 - .14
Damar, Batavia, cases, lb.	.10 - .22	.10 - .20	.08 - .24
Kauri, cases, lb.	.18 - .60	.18 - .60	.18½ - .60
Kieselguhr (f.o.b. mines), ton.	7.00 -40.00	7.00 -40.00	7.00 -40.00
Magnesite, calc, ton	64.00 -.....	65.00 -.....	65.00 -.....
Pumice stone, lump, bbl., lb.	.05 - .07	.05 - .08	.05 - .07
Imported, casks, lb.	nom	nom	.03 - .04
Rosin, H., 100 lb.	3.39 -.....	3.83 -.....	2.52 -.....
Turpentine, gal.	.67 -.....	.70½ -.....	.47½ -.....
Shellac, orange, fine, bags, lb.	.43 -.....	.43 -.....	.34 -.....
Bleached, bonedry, bags, lb.	.40 -.....	.40 -.....	.31½ -.....
T. N. Bags, lb.	.32 -.....	.32 -.....	.24 -.....
Soapstone (f.o.b. Vt.), bags, ton.	10.00 -12.00	10.00 -12.00	10.00 -12.00
Talc, 200 mesh (f.o.b. Vt.), ton.	8.00 - 8.50	8.00 - 8.50	8.00 - 8.50
200 mesh (f.o.b. Ga.), ton.	6.00 - 8.00	6.00 - 8.00	7.50 -11.00

Industrial Notes

IMPERIAL CHEMICAL INDUSTRIES, LTD., New York, on May 1, moved its offices to 521 Fifth Ave.

WICKWIRE SPENCER STEEL CO., New York, has appointed E. C. Bowers district sales manager in the Buffalo district with headquarters in the Rand Bldg.

E. F. HOUGHTON & CO., Philadelphia, announces that effective May 1, the retail sales division of the Lubri-Zol Corp. of Cleveland has assigned its interests to the Houghton organization.

SCAIFE CO., Oakmont, Pa., has made A. V. Murray executive vice-president. R. C. Taylor has succeeded Mr. Murray as secretary and R. W. Thrasher has been named plant superintendent.

AMERICAN-MARIETTA CO., Chicago, has transferred Charles P. Gilkson from Minneapolis to the main office where he will act as assistant to Roland G. Maus, sales manager.

AMERICAN K. A. T. CORP., New York, because W. P. B. has taken over its former office space is now located at 331 Madison Ave.

MONSANTO CHEMICAL CO., St. Louis, has transferred its accounting and treasury departments to the Shell Bldg. The space released will be used for the company's priorities and critical materials procurement section.

ROBINS CONVEYING BELT CO., Passaic, N. J., has appointed John M. Lupton advertising manager to relieve Alfred S. Otton for direction of production and sales of the screen cloth department.

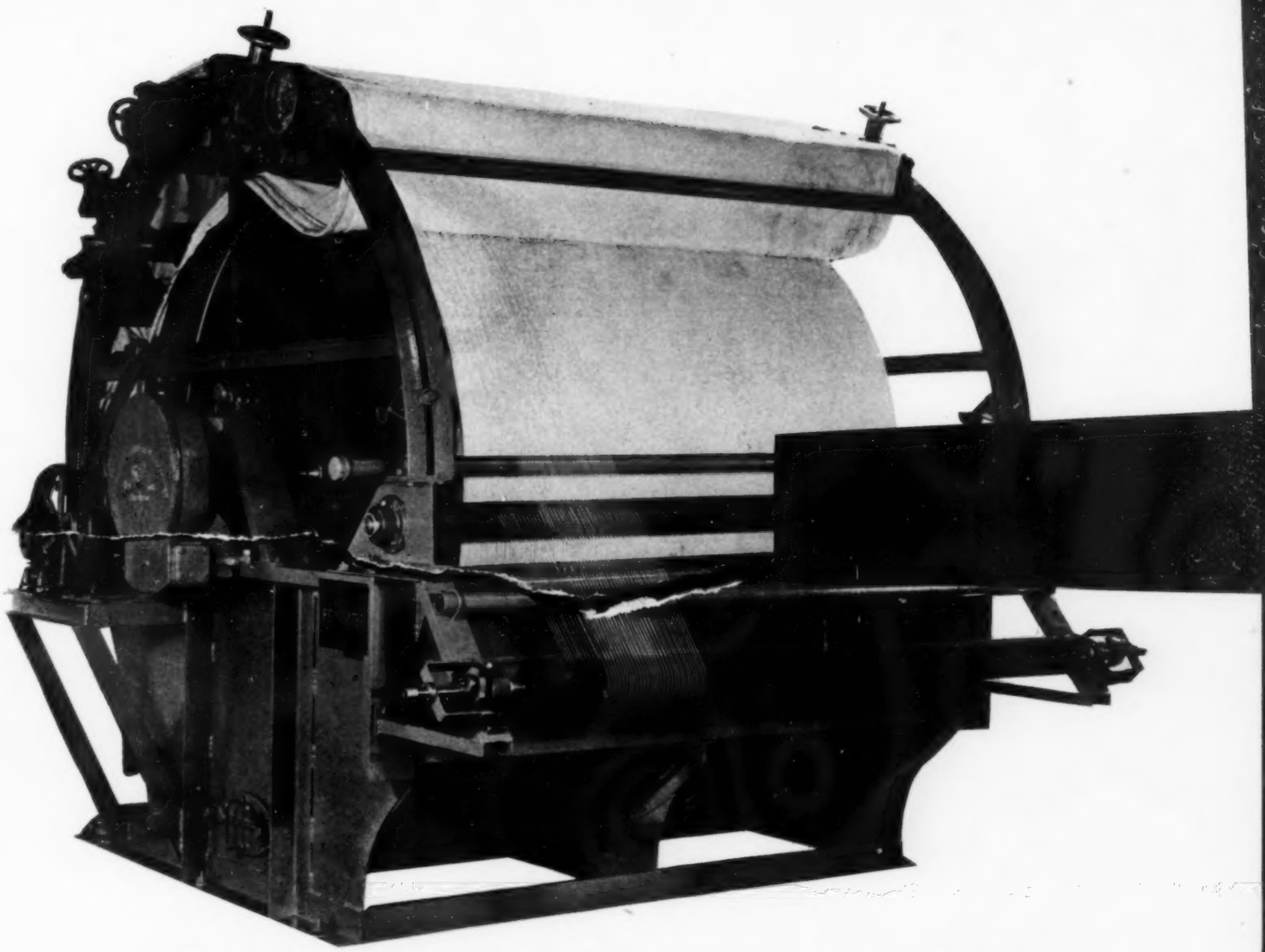
WILSON & GEO. MEYER & CO., San Francisco, has moved from the Federal Reserve Bank Bldg. and taken the entire fifteenth floor at 333 Montgomery St.

PENNSYLVANIA SALT MFG. CO., Philadelphia, has added C. W. Dermitt to its heavy chemical sales division in Pittsburgh.

TUBE TURNS, Louisville, has appointed W. E. Geiser as district manager in the Philadelphia office in the Broad Street Station Bldg. The company also has opened an office in the Commerce Bldg., Houston, Texas, with W. B. Whenthoff in charge.

FOOD MACHINERY CORP., Los Angeles, through its Peerless Pump Division, has acquired the Sterling Pump Corp. of Hamilton, Ohio, and Stockton, Calif. The Hamilton plant will be consolidated with the Peerless plant at Canton and the Stockton plant will be merged with the John Bean Mfg. Division at San Jose.

E. I. DUPONT DE NEMOURS & CO., Wilmington. The R. & H. Chemicals Department, has moved Edward W. McGovern from the chlorine products division to act as manager of the solvents division. Nelson C. Cooper has been transferred to the chlorine products division and M. Marean is now assistant to the director of sales.



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CHEM & MET NEW CONSTRUCTION

	Current Projects		Cumulative 1942	
	Proposed Work	Contracts	Proposed Work	Contracts
New England	.....	$3,305,000	$2,550,000	$620,000
Middle Atlantic	$740,000	6,380,000	6,181,000	46,848,000
South	6,000,000	1,000,000	9,305,000	29,233,000
Middle West	51,330,000	32,635,000	79,875,000	53,855,000
West of Mississippi	81,730,000	2,800,000	152,367,000	88,340,000
Far West	40,000	20,000,000	4,975,000	93,407,000
Canada	270,000	180,000	5,352,000	1,650,000
	$140,110,000	$66,280,000	$260,605,000	$313,953,000

Calif., Richmond—General Chemical Co., 400 Sansome St., San Francisco, has purchased a 40 acre site and plans to construct a new plant. Estimated cost will exceed $40,000.

Ill., Chicago—Galvin Manufacturing Corp., 4545 West Augusta Blvd., will soon award the contract for a 2 story, 120x140 ft. research laboratory. V. L. Charn, 141 West Jackson Blvd., Archt.

Ill., Jacksonville—National Enameling & Stamping Co., Granite City, will soon receive bids for the construction of an addition to its plant. Estimated cost including equipment $1,250,000.

Indiana—Standard Oil Co. of Indiana, 1915 Front St., and Carbon & Carbide Chemical Corp., Standard Ave., both of Whiting, contemplate the construction of a plant. Estimated cost $50,000,000.

Ia., Tama—Iowa Wood Preserving Co., Tama, plans to construct a wood preserving plant.

Kan., Kansas City—Phillips Petroleum Co., Bartlesville, Okla., plans to construct a plant.

N. J., Boonton—Norda Essential Oil & Chemical Co., 601 West 26th St., New York, N. Y., plans to alter its factory on Fanny Rd. Estimated cost will exceed $40,000.

N. J., Irvington—Irvington Varnish & Insulation Co., 6 Argyle Pl., is having plans prepared by Epple & Kahrs, Archts., 17 Washington St., Newark, for the construction of a 1 story, 100x100 ft. plant.

N. J., Newark—New Jersey Galvanizing & Tinning Works, foot of Pacific St., will soon award the contract for the construction of a 1 story, 165x177 ft. plant on Haynes Ave. V. Strombach, 1243 Springfield Ave., Irvington, Archt.

O., Wellsville—McClain Fire Brick Co., Wellsville, plans to construct an addition to its plant.

Pennsylvania—Stupakoff Ceramic & Manufacturing Co., Latrobe, will soon receive bids for the construction of a factory. Estimated cost will exceed $500,000.

Pa., Erie—Hammermill Paper Co., E. E. Behrend, Pres., East Lake Rd., will soon award the contract for the superstructure of a 1 story, 40x50 ft. addition to its boiler house. O. C. Schoenwerk, 3240 North Lake Shore Dr., Chicago, Ill., Consult. Engr. Estimated cost $80,000.

Pa., Gettysburg—Central Chemical Corp. of Pennsylvania, S. G. Spangler, Mgr., plans to rebuild its 2 and 3 story, 55x250 ft. plant recently destroyed by fire. Estimated cost will exceed $40,000.

S. D., Yankton—Schwenk Brewing Co., Yankton, plans to remodel brewery here into plant for the production of alcohol. Estimated cost $150,000.

Texas—Neches Butadiene Products Co. contemplates the construction of a plant. Estimated cost $72,000,000.

Texas—Republic Oil & Refining Corp., Texas City, contemplates the construction of a refinery. Estimated cost $7,000,000.

Tex., Port Arthur—Texas Co., 720 San Jacinto St., Houston, will soon award the contract for the construction of a manufacturing plant. Estimated cost $2,500,000.

B. C., Vancouver—Basic Magnesium, Inc., 735 Hanna Bldg., Cleveland, O., plans to construct a plant here. Estimated cost $50,000.

N. S., Yarmouth—Syndicate c/o Mayor, Town Hall, plans to construct a plant for the manufacture of oils, etc. Estimated cost $40,000.

Ont., South River—Standard Chemical Co., Ltd., 67 Yonge St., Toronto, Ont., plans to construct an addition to its plant here.

Ont., Toronto—Canadian Synthetic Rubber, Ltd., c/o K. E. Kennedy, Port Credit, plans to construct a plant. Estimated cost $50,000.

Ont., Toronto—Modern Plating Co., Ltd., c/o E. N. Johnson, 26 West Adelaide St., plans to construct a plant for enameling, coating and plating of metals. Estimated cost $40,000.

Que., Coleraine—Mutual Chemical Co., Ltd., plans to construct a hemp mill here. Estimated cost $50,000.

CONTRACTS AWARDED

Connecticut—New England Lime Co. has awarded the contract for the construction of a plant to Lindholm Construction Co., Pittsfield, Mass. Estimated cost between $2,000,000 and $3,000,000.

Conn., Stamford—American Cyanamid Co., C. Kennedy, 1937 West Main St., has awarded the contract for the construction of a 1 story plant addition to Cuzzi Bros. & Singer, Inc., 10 South Second Ave., Mt. Vernon, N. Y. Estimated cost $40,000.

Ill., Aurora—United Wall Paper Factories, Inc., 5701 West 66th St., Chicago, has awarded the contract for the construction of a factory to Carl W. Linder, 243 South River St., Aurora. Estimated cost $60,000.

Md., Baltimore—Standard Oil Co. of New Jersey, Standard Oil Bldg., has awarded the contract for a processing plant to M. W. Kellogg, 225 Bway., New York, N. Y. Estimated cost $320,000.

Mass., Southbridge—American Optical Co., 14 Mechanic St., has awarded the contract for a 1 story, 200x720 ft. factory to H. P. Cummings Construction Co., 14 Prospect St., Ware. Estimated cost $425,000.

Michigan—Headquarters of Dow Chemical Co., Midland, has awarded the contract for the construction of a plant to Austin Co., 429 Curtis Bldg., Detroit. Estimated cost $20,000,000.

New Jersey—U. S. Rubber Co. has awarded the contract for the construction of a plant to Thompson-Starrett Co., Inc., 44 Madison Ave., New York, N. Y. Estimated cost less than $1,000,000

N. J., Hillside (branch of Elizabeth)—Union Carbide & Carbon Co., 30 East 42 St., New York, N. Y., has awarded the contract for a 1 story, 53x81 ft. plant to Oschwald Construction Co., 854 Clinton Ave., Newark. Estimated cost $40,000.

N. Y., New York—Headquarters of Carbide & Carbon Chemical Corp., 30 East 42nd St., has awarded the contract for the construction of a plant to Ford, Bacon & Davis, 39 Bway., New York. Estimated cost will exceed $5,000,000.

Ohio—Atmospheric Nitrogen Corp., 61 Bway., New York, N. Y., will construct a plant here using its own forces. Estimated cost will exceed $10,000,000.

Ohio—Vanadium Corporation has awarded the contract for the construction of a plant to Rust Engineering Co., Clark Bldg., Pittsburgh, Pa. Estimated cost $2,500,000.

O., Cleveland—Cleveland Graphite Bronze Co., c/o F. Salzman, Engr., 16800 St. Clair Ave., has awarded the contract for a 1 story, 100x250 ft. plant addition to A. M. Higley Co., 2036 East 22nd St. Estimated cost $75,000.

R. I., Cranston—Air Reduction Sales Corp., 60 East 42nd St., New York, N. Y., has awarded the contract for a 1 story, 95x108 ft. and 25x45 ft. plant to Central Engineering & Construction Co., 210 Main St., Pawtucket, R. I.

South Carolina—Pittsburgh Metallurgical Co., Inc., Oliver Bldg., Pittsburghm Pa., plans to construct a plant using its own forces. Estimated cost will exceed $1,000,000.

Tex., Conroe—Superior Oil Co., Conroe, has awarded the contract for the construction of a refinery of Fluor Corporation, Ltd., Esperson Bldg., Houston. Estimated cost $2,800,000.

Vt., Brattleboro—American Optical Co., 14 Mechanic St., Southbridge, Mass., has awarded the contract for superstructure for 1 story, 160x420 ft. factory to H. P. Cummings Construction Co., 14 Prospect St., Ware, Mass. Estimated cost $300,000.

Washington—Electro Metallurgical Corp., subsidiary of Union Carbide & Chemical Corp., has awarded the contract for the construction of a plant to H. K. Ferguson Co., Hanna Bldg., Cleveland, O. Estimated cost $20,000,000.

Ont., Smithsville—H. Smith Paper Co., Ltd., 407 McGill St., Montreal, Que., has awarded the contract for an addition to its plant here to A. F. Byers Construction Co., Ltd., 1226 University St., Montreal. Estimated cost $40,000.

Que., Forestville—Anglo-Canadian Pulp & Paper Co., Ltd., Quebec City, plans to construct an addition to its plant. Estimated cost $100,000.

Que., Montreal—Dominion Oilcloth & Linoleum, Ltd., 101 Parthenais St., has awarded the contract for an addition to its plant to Cook & Leitch, 1440 Ste. Catherine St. Estimated cost $40,000.